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Enhancing Regional Resilience for Energy Price Shocks: Efficient Gas Use and Upstream Decarbonization

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Enhancing Regional Resilience for Energy Price Shocks: Efficient Gas Use and Upstream Decarbonization

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Abstract

Resilience and competitiveness in relation to fossil energy dependencies is of increasing concern to industries and policy makers. We investigate to what extent the competitive position of industries in European regions are sensitive to changes in fossil fuel prices, and whether reductions in gas use along the value chain may increase regional industry resilience. A new spatial revealed cost competition model based on the input-output price model is used and calibrated to multi-regional world input-output tables on an EU NUTS 2 level. We obtain elasticities of fossil fuel prices on revealed cost competitiveness and analyze how they are affected by increased efficiency and electrification in production. We show that European regions are resilient to global coal price increases, whereas they are vulnerable to gas price shocks. The transition towards using less gas in production, by efficiency improvements or electrification, can reduce these gas price vulnerabilities. However, when competitors become more efficient instead, the vulnerability to such shocks may increase. Decarbonizing upstream sectors like electricity generation in the own region, own country or in Europe, can increase resilience of downstream industrial sectors in most European regions.

Keywords: Competitiveness, regional resilience, fossil fuels, energy efficiency, global value chains, input-output analysis

JEL Codes: F18, Q41, R11, R15

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1 Introduction

In recent years, there have been notable fluctuations in energy prices resulting in cost increases in energy-using firms. The Ukrainian-Russian conflict and the following spike in gas prices have made the dependency of economies on gas a reason for concern as competitiveness of the Euro area decreased (Chiacchio et al., 2023). While natural gas price projections indicate relatively modest anticipated rises in prices, the volatility in these projections is pronounced. The gas market is sensitive to shocks and geopolitical tensions, resulting in increased uncertainty regarding price developments (IEA, 2023). Due to specialization in regional economies in energy-intensive industries or production processes, increasing regional resilience to shocks is becoming an important policy objective to limit the potential damages from future shocks. Meanwhile, policies addressing industrial ecology, such as the transformation of the energy system may alter this sensitivity to fossil fuel prices. Regional resilience in terms of the competitive position could therefore be increased by alterations in the energy consumption in industrial production and upstream sectors, which relates to Hoffman et al. (2014) and Esty and Porter (1998), discussing industrial ecology as a source of competitive advantage at the firm level.

In this paper, we analyze the sensitivity of regional competitiveness to changes in fossil fuel costs and explore how efficiency and electrification can increase competitive resilience. We develop a model for revealed cost competition (RCC), which fully integrates an input-output price model into the model of revealed competition developed in Thissen et al. (2013). Subsequently, we derive the price elasticity of the RCC of industries in regions to changes in fossil fuel costs. This elasticity describes the region-specific competitive threats and opportunities (or resilience) for these industries. Furthermore, we examine the change in this elasticity that describes how technological advancements and substitutions among different energy types impact the resilience. This way, we gain insights into the intricate relationships between energy price fluctuations and competitive dynamics of technological advancements resulting in shifts in energy types at the regional and industry levels. The analysis is based on a multi-regional world input-output table at the EU NUTS 2 level, as outlined in Thissen et al. (2018), extended with energy accounts.

The results of this paper provide us with a deeper understanding of the competitive dynamics within regions, due to the sectoral specialization of the region and competitive positions in global value chains. We show that regions in Europe are resilient to global coal price increases, suggesting a low dependency on coal, whereas they are more vulnerable to natural gas price shocks in terms of their competitive position. The size of the total effect on the regional industrial competitiveness in the case of a global gas price shock is negative only in a few regions, due to a dependence on energy-intensive industries or reliance on gas in industrial processes. For example, regions in the Netherlands are vulnerable to global gas price shocks, due to dependency on gas in electricity generation and a historical pattern of gas intensity in production. Hamburg in Germany, due to specialization and a large chemical industry sector, is also negatively affected. Meanwhile, the traditional materials sector in the European regions, including basic metals production, is very competitive. In the case of a European end-user price shock in either gas or coal, all EU regions lose in terms of their competitiveness.

Additionally, we examine how decarbonization can present opportunities for these regions to reduce their sensitivity and enhance their resilience for gas price shocks. In the case of efficiency improvements in the use of gas or electrification in the production process of industrial products in the own region, this always increases resilience to future price shocks. At the same time, the results show that if competitors become more efficient in the use of gas (e.g., get closer to the technological frontier), this could decrease resilience. It is therefore important to not stay behind in such improvements to limit negative effects of future gas price shocks.

Efficiency improvements or electrification upstream can affect the resilience of downstream industrial sectors, due to the decreased indirect use of gas. We find that increasing the efficiency of the use of gas in electricity generation and oil refinery and cokes production within the same region, country or in Europe, can increase resilience for the low- and medium-tech industry in most European regions.

The paper is structured as follows. In Section 2 an overview of the literature is provided and the various concepts used are defined. In Section 3 the model is presented. In Section 4 the data used for the analysis are described. Section 5 presents the price elasticities and decarbonization effects. Finally, in Section 6, we conclude.

2 Background

In this section, related studies are introduced to support the method used and research question addressed here. Afterwards, the concepts '*competitiveness*' and '*resilience*' as used in our framework are defined, compared with the literature, and explained.

2.1 Related literature

Studies discussing the regional economic effects of changing energy prices became prevalent in the period of the oil crisis in 1973. Miernyk (1976a,b) describes the regional consequences of high energy prices in the U.S. and develops a cost-push price model to investigate the cost pass-through and changes in value-added per region from the energy price changes between 1967 and 1974. Energy-consuming regions are found to experience a shift in the inter-regional terms of trade, having to pay more for the products they are importing. On the other hand, energy-producing regions are expected to gain. Similarly, Polenske (1979) uses a multi-regional input-output price model to study the cost pass-through studying the same fossil fuel price increase. Wu et al. (2013) use an input-output price model adjusted for price stickiness in China to evaluate the effect of oil price pass-through in inflation. Input-output models are thus often used to study fossil fuel cost change effects on regional economic outcomes, as they provide an idea of the structure of the regional economy and the pass-through of the increased prices on other sectors through trade networks.

More recently, studies have investigated the effect of rising oil, gas and coal prices on competitiveness, measured in terms of exports, imports or value-added. Capros et al. (2016) investigate competitiveness effects in the EU of gas and electricity price increases using a general equilibrium model, where competitiveness is measured based on changes in imports and exports. They find that energy-intensive sectors that are more exposed to foreign competition, such as chemicals and non-ferrous metals, are more negatively affected in terms of competitiveness. Valadkhani and Mitchell (2002) study petrol price increases in Australia using a modified input-output price model and investigate resilience to such shocks. Comparing the analysis for 1977-78 with the same analysis for 1996-97 shows that the Australian economy has become less sensitive to fossil fuel price shocks. More recently, Wang (2022) studied the effect of energy price fluctuations on regional growth using panel data for 30 Chinese regions, and finds that the effects across regions depend on the initial production structure.

Similarly, various studies have investigated the effect of climate policy or carbon prices on competitiveness (see Dechezleprêtre and Sato, 2017, for a review of empirical evidence). For example, using the World Input-Output Database (WIOD) and the carbon-content of products, Ward et al. (2019) investigate competitiveness after a world-wide carbon tax. Countries with a low carbon-intensive energy system see an increase in competitiveness, which is defined as the international demand change for the exported products from the price increase.

Regional economies are more specialized in terms of their production structure compared to national economies, and therefore can be more vulnerable to energy price shocks. Previous regional studies show that the production structure of a region determines its vulnerability to energy price fluctuations (Wang, 2022; Miernyk, 1976b,a). Meanwhile, research suggests that resilience of regions could increase as renewable energy markets are more geographically dispersed (see e.g. Scholten et al., 2020; IRENA, 2019; Bridge et al., 2013). However, studying the regional economic effects of an increasing market share of renewables is complicated due to data limitations. An example of including renewables in an input-output methodology is Többen (2017), who studies the regional effects of the promotion of renewable energy policy in Germany using. In our analysis, we implicitly consider efficiency and electrification and investigate the effect on regional competitive resilience, as industrial ecology could affect competitiveness of firms (Hoffman et al., 2014; Esty and Porter, 1998).

2.2 Competitiveness and resilience

Within our framework, a region's *competitiveness* is defined by the concept of revealed competition, which is based on the trade network of regions in global product markets (Thissen et al., 2013). Here, revealed competition is rooted in a spatial interpretation of competition, where suppliers from specific regions sell their products on sales markets in other regions. Consequently, competition occurs between suppliers from distinct regions on these sales markets. This measure was previously applied to analyze the impact of Brexit (Thissen et al., 2020), and in this study, it is applied to assess the potential impact of cost changes due to increasing fossil fuel prices.

Our concept of revealed competition differs from competitiveness measures based on the Balassa index (Balassa, 1965), which assesses a country's competitiveness based on its specialization in industries measured by gross exports compared to other countries. Other measures, such as the one proposed by Timmer et al. (2013), replace gross exports with global value chain (GVC) income to account for the overestimation of competitiveness caused by imported intermediates. By incorporating GVC income, this index shifts the focus from export share to a country's contribution to international global value chains. This is an improvement over export-based indices that fail to consider the modern organization of production processes, which involves numerous small value-adding activities required to produce a final manufacturing product. Los et al. (2016) utilize this index to examine the competitiveness of EU regions, and both Timmer et al. (2013) and Los et al. (2016) argue that countries with a high concentration of value-added activities in specific production processes within GVCs are more competitive than others.

While Balassa-based indices concentrate on the outcome of the competitive process, the revealed competition measure utilized in this analysis centers on how cost changes may affect the competitive position of industries in regions. These concepts are not directly comparable and rely on distinct assumptions. For instance, whereas GVCs analyses rely on static value chains, the concept of revealed competition is focused on the competition within the value chain where distinct firms in distinct locations compete to be a part of the value chain. Additionally, the concept of revealed competition is focused on spatial markets where competition occurs on regional and product-specific spatial scales, whereas GVC analyses consider solely a global market with local suppliers participating in global competition.

The measure of revealed competitiveness is used to study to what extent a region can increase its *resilience* by decarbonizing. As described by Scott (2013); Martin (2012); Meerow and Newell (2015) competitiveness is a long-run, path-dependency phenomenon, whereas resilience relates to the short-run ability of regional economies to bounce back from a shock (also referred to as 'equilibrium resilience'). A different way of looking at resilience is 'evolutionary resilience' or 'ecological resilience': the shock allows the region to move towards a new equilibrium, realizing new growth paths, or 'bounce forward' (Martin, 2012; Boschma, 2014; Meerow and Newell, 2015). Meerow and Newell (2015) conclude, based on a biblometric review, that quantifications of characteristics of resilience are scarce. In our study, we therefore provide a novel method to study resilience of the industrial sector of regions. We investigate whether decarbonization can be a way to increase the evolutionary resilience of regions in a quantitative manner. In the first part of the analysis, a change of the regional competitiveness (e.g. the vulnerability) informs us about the 'equilibrium resilience' of a region. However, in the second step of the study, the decarbonization scenarios indicate a different equilibrium where the vulnerability may be smaller or larger, indicating the 'evolutionary resilience': decarbonization may help a region to 'bounce forward' after the shock and thus increase resilience. Important to note, however, is that the underlying mechanisms or dynamics from moving from one equilibrium to another are not endogenous in our framework.

3 Model

We use a model for revealed competition developed in Thissen et al. (2013) and combine this with an input-output price model (see Miller and Blair, 2009). This is comparable to the price competition model used in Thissen et al. (2020), however, here we fully integrate both models into one model for revealed cost competition (RCC). The integration into one model allows us to directly analyze the effect of, for instance, policies or technological changes on the cost competitiveness of industries in specific regions.

The model is used for a two-step analysis, presented in Figure 1: First, we study the effect of a change in the fossil fuel costs on the RCC, obtaining a price elasticity on the competitiveness.

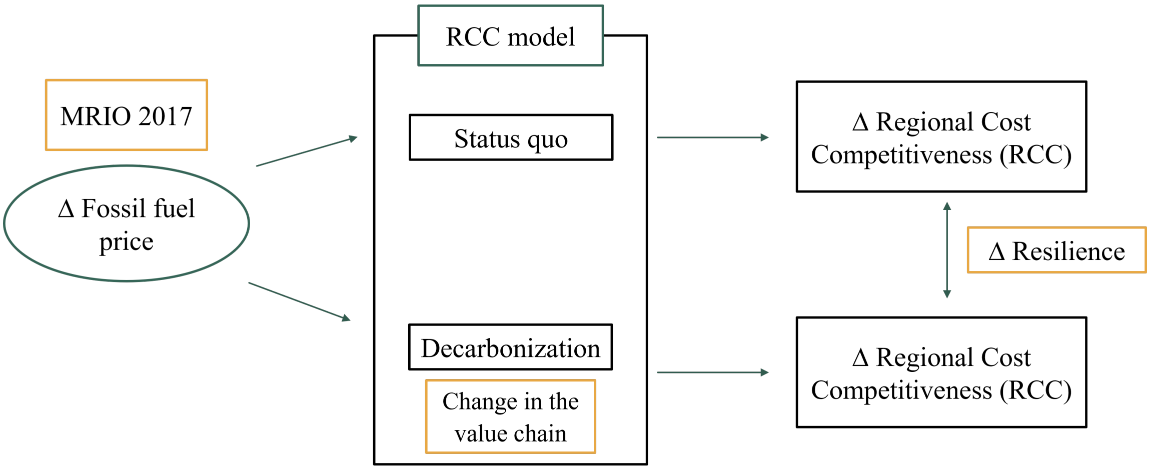

Figure 1: A graphical representation of the analysis. The Δ represents a change in the specified variable, MRIO is short for multi-regional input-output table, and RCC refers to revealed cost competition.

This follows the methodology of using marginal prices in a revealed competition model also used by Thissen et al. (2020) to determine the effect of tariffs in case of a Brexit.

Second, we study the effect of decarbonization strategies on regional resilience. Here, we use a novel approach of studying marginal changes on the technological coefficients in the input-structure of products. This can be seen as investigating slight adjustments in the production structure of firms. In combination with the previous method of studying the effect of fossil fuel costs, we study different equilibria and the resulting price elasticity on the RCC informs us of the new 'equilibrium resilience'. Comparing the baseline outcome with these scenarios informs us of the 'evolutionary resilience' of regions.

3.1 Measuring regional revealed cost competitiveness

The model for regional cost competitiveness (RCC) uses the revealed *spatial* competition concept from Thissen et al. (2020) to determine the relative cost change effect of a price change of an industry in a region relative to its revealed competitors. This measure of revealed cost competitiveness takes into account value chain linkages and the competitive position of the region on the various product markets. Changes in prices are compared to the price changes of the most important competitors, and this is reflected in the revealed cost competitiveness measure.

The principle of revealed competition takes into account the size of the sales market and the overlap of regions in those sales markets (for example, Dutch and German regions exporting to the same region in France). It determines the extent to which an industry in a region will sell the same product as an industry from another region in all the sales markets it sells its products. Simultaneously, the measure used also takes into account the size of the production within a region and thus the dependence of the regional economy on this particular product market. Thus, the final measure of regional competitiveness is given by:

$$RC_{i,r,r'} = \sum_{r''} s_{i,r,r''} m_{i,r',r''}, \qquad (1)$$

where i indicates a product and r and r' the various regions. The regional competition of product i between region r and r' is given by the product of the sales market share ($s_{i,r,r''}$) of region r for product i in region r'' times the market share ($m_{i,r',r''}$) of this product i in region r' exporting to region r''. We define the market share:

$$m_{i,r,r'} = \frac{x_{i,r,r'}}{\sum_{r'} x_{i,r,r'}}. \tag{2}$$

Thus, for the market share for product i between region r and r', we look at the production (given by $x_{i,r,r'}$) of good i in region r that is going to region r', over the total 'foreign' demand for this good produced in region r. The weighting of sales markets by the market share ensures that competition between industries from two regions is not symmetric.

The sales market share is computed as:

$$s_{i,r,r'} = \frac{x_{i,r,r'}}{\sum_{r} x_{i,r,r'}}. \tag{3}$$

The market share of an industry in a region represents its sales as a share of size of the market (the total sales in that market) in the denominator. This implies that we sum up the production of good i that is being consumed in region r' over all regions that it may be coming from. Thus, this is the total size of the sales market of good i in region r'. We compute the share by considering the amount of products i that is produced in region r that is being sold in region r' over the total size of the sales market. Therefore, if the sales market share is large, this implies that the production of good i from region r is very dominant in region r'.

The regional cost competitiveness considers how a change in a price for a product or region affects the regional competitiveness through GVCs, in combination with the own-price effect. This results in:

$$RCC_{i,r} = \frac{\sum_{r'} p_{i,r'} \sum_{r''} s_{i,r,r''} m_{i,r',r''}}{p_{i,r}}. \tag{4}$$

This measure considers a full pass-through of price increases along the value chain, assuming perfect competition, based on the revealed competition and revealed spatial trade network. In the case of imperfect competition and market power, industries may be able to absorb some of the input products price increases or substitute between inputs and thus the pass-through may be less than 100%. However, when considering short-term effects and large geographical price shocks, a full pass-through can be indicative of vulnerabilities to fossil fuel energy price spikes.

3.2 The Revealed Cost Competition model

The revealed cost competition model combines the revealed cost competition measure from Equation (4) with the input-output price model (presented in Miller and Blair, 2009). For the base year index prices, the system of equations looks like:

$$p_{i,r} = \sum_{j,r'} p_{j,r''} a_{j,r',i,r} + v_{i,r}, \tag{5}$$

where $v_{i,r} = \frac{va_{i,r}}{x_{i,r}}$, the cost of production factor inputs per unit of output. Thus, changes in input prices lead to changes in sectoral unit costs via the fixed technical coefficients, $a_{j,r',i,r}$.

To compute the effect of price changes on the RCC, we maximize the RCC for a specific industry in a region under the constraint of Equations (2) to (5). Using this non-linear programming technique provides us with marginal values on fossil fuel prices which inform us about the *price elasticities*[1]:

$$\eta^p_{i,r} = \frac{\partial RCC_{i,r}}{\partial v_{j,r}} \frac{v_{j,r}}{RCC_{i,r}}. \tag{6}$$

To study the effect of efficiency and electrification on resilience to fossil fuel price shocks, we use a novel approach where we study marginal changes on the technological coefficients. Thus, we compute the change in the price elasticity with respect to the technological coefficient $a_{j,r',i,r}$, which can be interpreted as the change in resilience:

$$\epsilon_{j,r',i,r} = \frac{\partial \eta^p_{i,r}}{\partial a_{j,r',i,r}} a_{j,r',i,r}, \tag{7}$$

where we define $\epsilon_{j,r',i,r}$ as a semi-elasticity, such that we can interpret it as a percentage change in the use of a good in production.

By adding constraints on how the technological coefficients are allowed to change, we consider two scenarios focused on reducing the dependency on natural gas: (1) an increase in the overall use of gas efficiency of the production process, simply reflected by Equation (7) and (2) an electrification scenario, where the use of a gas can only be substituted for electricity from the own region.

4 Data

We create detailed Supply and Use tables (SUTs), and a multi-regional input-output (MRIO) table, by disaggregating the regional SUTs from Thissen et al. (2023) to isolate fossil fuels as separate products. Using a detailed MRIO table which distinguishes fossil fuels as direct and indirect inputs into production in various industries allows us to study dependencies on fossil fuels through the value chain.

The rows of the original SUTs are split up, where these disaggregated SUTs by design sum up to the original tables and are fully balanced. We make use of various detailed data sources, such as the SUTs of the U.S. and Japan, IEA World Energy Balances database, BACI trade flow data, and regional structural business statistics from Eurostat. A description of the method applied is presented in Section 6. We aggregate the resulting product-by-product MRIO table to the products: *agriculture, traditional materials, high-tech industry, low- and medium-tech industry, chemical industry, oil refinery and cokes production, coal, oil, gas, electricity, other energy, private services, public services and transport*, see Table 1 in the appendix. The table is aggregated to the NUTS 2 regions within a country (included countries: Austria, Belgium, Germany, Denmark, Spain, France, The Netherlands, Italy, Poland and Portugal),

[1] Technically, we model the price increase as a percentage change in the value-added component of the price, or the returns to fossil fuels.

other countries in the EU and the various countries in the rest of the world[2]. Using this method, the resulting MRIO table contains industry-region-specific energy intensities in production and regional-level trade flows.

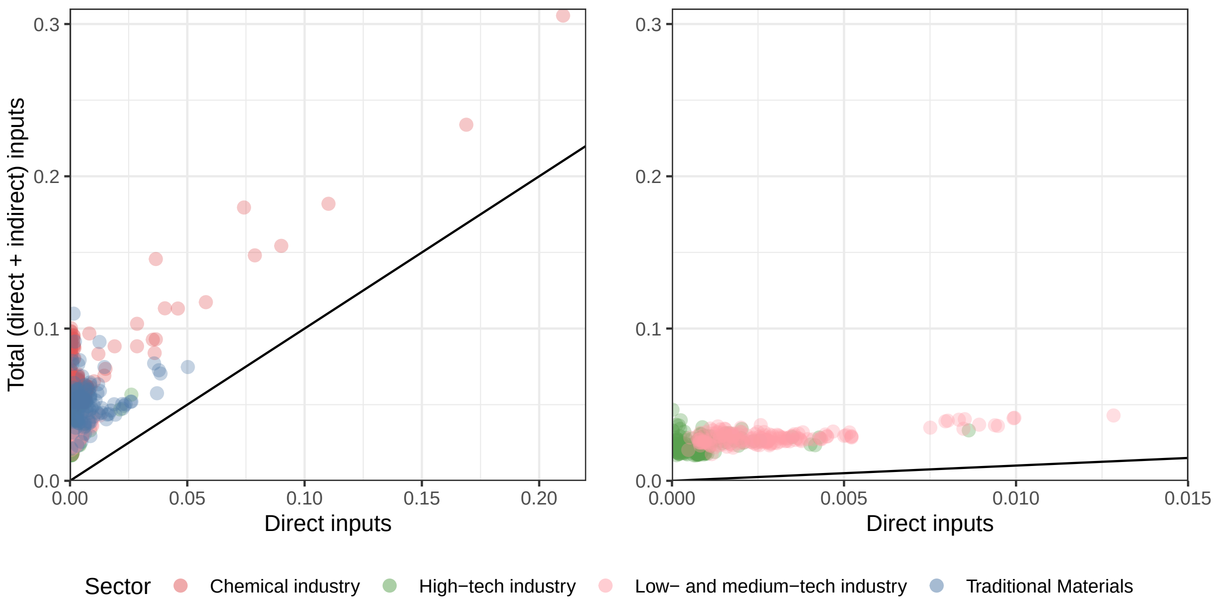

Figure 2: Fossil inputs in production per sector (in Euros per 1 Euro of production).

Note: *The resulting direct use of fossil energy per NUTS 2 province per sector plotted against the total use of fossil energy throughout the value chain. On the left-hand side all sectors are included, while on the right only the sectors high- and low- and medium-technology industry are plotted. A 45-degree line is included in both figures. In the appendix, the plots for separately coal and gas are included in Figures 11 and 12.*

Figure 2 shows the resulting direct fossil energy use per product on the horizontal axis, and the total energy use throughout the value chain on the vertical axis. Each data point represents a product-region combination. In terms of fossil fuel intensity in production, the chemical industry and traditional materials industry products are most fossil-intensive. However, while substantial direct energy consumption is a necessary condition for sensitivity to price shocks, it alone is not sufficient to have a significant impact on cost competitiveness. To have a substantial effect on cost competitiveness, it is also crucial for an industry to demonstrate differences in energy usage compared to its competitors. In Figures 13 to 15, maps are included to show the regional distribution of fossil fuel intensity per product per European NUTS 2 region.

5 Results

First, we present the price elasticities of the revealed cost competitiveness in the current state of the world (e.g. the measure of 'equilibrium resilience'). We study a global price increase for gas and coal, and a European tax or price increase on the use of these energy sources in

[2]The regional aggregation used includes the regions/countries: all European countries, NUTS 2 regions ITC4 (Lombardia), FR10 (Île-de-France), UKI (London), Russia, Saudi-Arabia, U.S., China, India, Japan, rest of the world.

products. Second, we analyze how these price elasticities are affected by changes in the energy use, e.g. whether resilience increases or decreases when the economy is becoming more green.

5.1 Global price shock

In the model, the sensitivity of a specific industry to a change in the gas or coal price is directly influenced by its energy intensity in production, plotted in Figure 2. Industries that heavily rely on energy will have their total production costs significantly affected by changing energy prices, creating conditions for substantial effects on cost competitiveness. The type of energy and the regions from which it is obtained are also crucial factors influencing the sensitivity of cost competitiveness. When a particular industry in a region utilizes a specific energy type obtained from a certain region, while its competitors employ different energy types or sources, the price competitiveness of that industry becomes highly sensitive to the price of the specific energy type it relies on and its specific source.

First, we study a global price increase of gas or coal, and thus the price change is independent of the regional source. The observed effects are therefore attributed to differences in usage type or production efficiency.

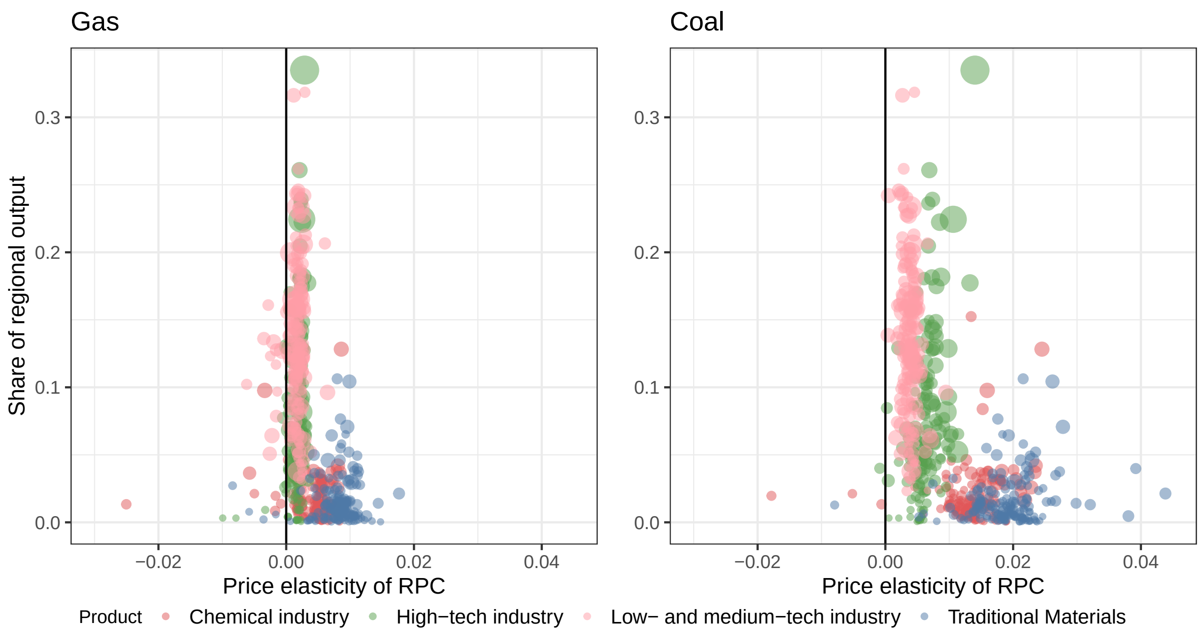

Figure 3: The elasticity of the global gas (left) or coal (right) price on the competitiveness of the European NUTS 2 regions.

> *Note*: *The elasticity can be interpreted as follows: a 1% global gas price increase results in a η% increase in the RCC. The size of the points reflects the value of production in the region in Euros. The y-axis reflects the share of the production value of the sector of the total production value in the region.*

The effect of a global price increase of coal or gas on the RCC of industries is heterogeneous but follows a strong sectoral pattern, as shown in Figure 3. A negative price elasticity implies that an increase in the global gas or coal price decreases the competitive position of the industry in the region under consideration. A positive value implies that the competitive position of the industry-region combination improves: the price increase of competitors is larger as they may be less efficient in their use of gas or coal ('technology effect') or the products produced may be different ('product mix effect').

Products with higher direct energy intensity are more severely affected by the price change in terms of their competitive position, as the size of the price elasticities (either positive or negative) are larger. The global gas price shock shows vulnerabilities and dependencies of certain regions for the use of gas in the production process in all sectors, but mostly in the chemical and low- and medium-technology industry as the price elasticities are negative. In the case of a global coal price shock, almost all regions considered are positively affected and thus competitive opportunities are created. This suggest a low dependency of the European regions on coal compared to competitors.

The traditional materials sector exhibits a notable sensitivity to changes in the coal price in a positive sense, and in most cases also for a global gas price change. This suggests that the European traditional materials sector is relatively efficient in its utilization of fossil fuels compared to its competitors, or that they face lower fossil fuel prices initially.

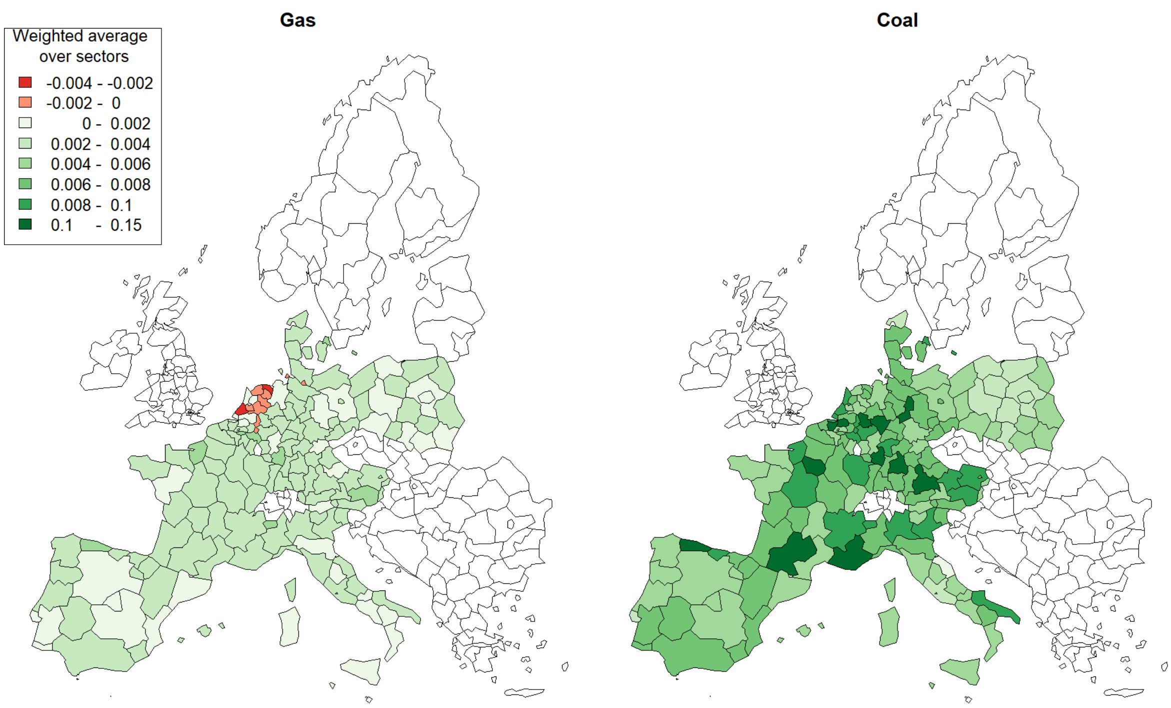

Figure 4: The elasticity of a global gas (left) or coal (right) price on the competitiveness of the European NUTS 2 regions.

Note: *The weighted average is computed over the production of the sectors traditional materials, low- and medium-technology industry, high-technology industry and chemical industry within the region.*

Figure 4 shows a weighted average of the price elasticities based on the production of the sectors in these regions. This provides the effect of the global price increase on the competitiveness of the industry sector in the region as a whole. In most regions, energy-intensive industries, like chemicals and traditional materials, which have larger price elasticities as shown in Figure 3, make up a smaller part of the regional output than the other two industrial sectors. Thus, the weighted average for the industrial sector as a whole is smaller for all regions, and mostly for regions that are more diversified in terms of their industrial production.

The vulnerabilities (negative price elasticities) observed for the industry low- and medium-technology products from Figure 3 mainly occur in the regions within the Netherlands, where the sector is highly dependent on gas. The region of Hamburg in Germany is also negatively affected, mainly due to the large vulnerability of the chemical industry. Maps for the sector-specific global price elasticities are included in Figures 17 to 19.

5.2 European price shock

Next, we study the effects on the regional cost competitiveness of an increase in European gas and coal user prices[3], respectively, which could be seen as a European-wide tax on the use of these fossils. This modeling exercise reflects the case of uncertainties surrounding government policies, for example regarding suggested policies like the EU Green Deal or sudden changes in the price of EU ETS certificates. Past fossil price spikes have been heterogeneous across regions and in this case competitiveness effects may be larger[4].

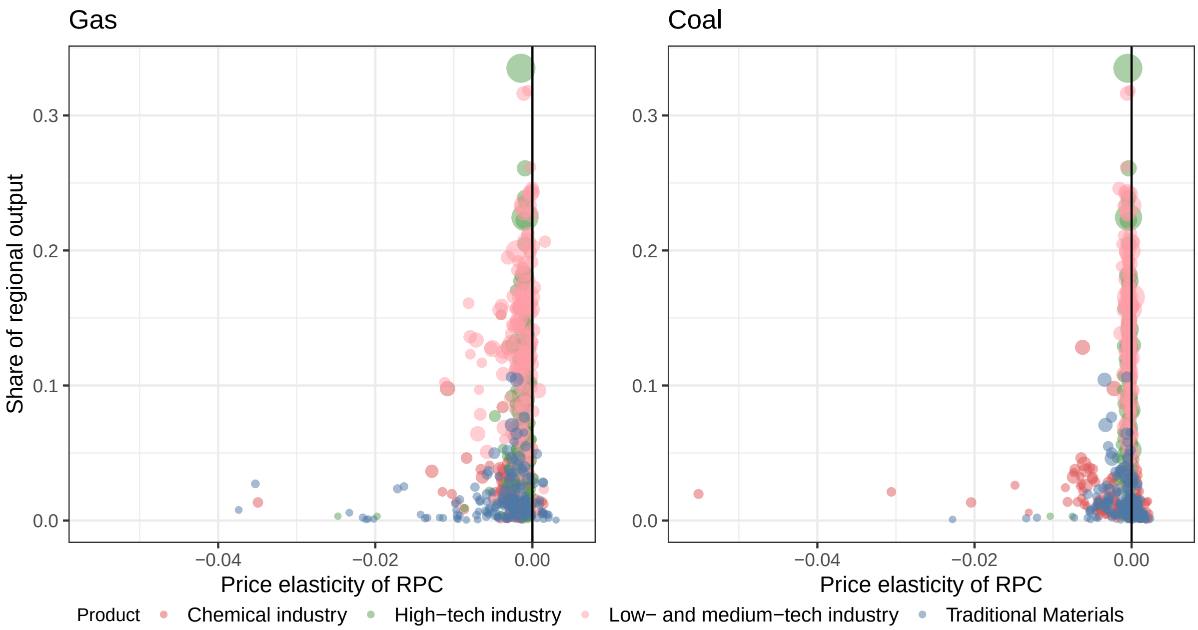

Figure 5: The elasticity of the price of using gas in Europe (left) or coal in Europe (right) on the competitiveness of European NUTS 2 regions.

> *Note*: *The elasticity can be interpreted as follows: a 1% industry gas price increase in Europe results in a η% increase in the RCC. The size of the points reflects the value of production in the region in Euros. The y-axis reflects the share of the production value of the sector of the total production value in the region. The price increase assumes that all fossil fuels used in production in European regions is 'taxed' or becomes more expensive.*

[3] Included in Europe trade block group assumed here are the countries: Cyprus, Switzerland, Malta, Luxembourg, Latvia, Croatia, Lithuania, Norway, Slovakia, Slovenia, Sweden, Romania, Portugal, Poland, Italy, Ireland, Hungary, France, Finland, Spain, Greece, Estonia, Denmark, Czech Republic, Bulgaria, The Netherlands, Austria, The United Kingdom and Belgium.

[4] This is equivalent to studying competitiveness effects of climate policies, as discussed by Dechezleprêtre and Sato (2017).

Figure 5 shows that as expected due to the cost increase, a price increase in Europe negatively affects the competitive position of European regions. The sectors low- and medium technology industry and high-technology industry in the regions are more vulnerable to a European price shock in gas than in coal: competitors are thus more dependent on coal in their production process than the European regions.

Again, we compute a weighted average for the regions, shown in Figure 6. Again, the regions that lose most in terms of their industrial sector competitiveness are regions with either more heavy industry and less diversification, or that as a whole depend on gas or coal in the industrial production. Reasons for other negative effects of the European price increase could be that regions are less intertwined in GVCs and mostly focused on the European market for the inputs into production. In the appendix, various maps are included that compare the global price elasticity with the case of the European price increase, see Figures 17 to 20.

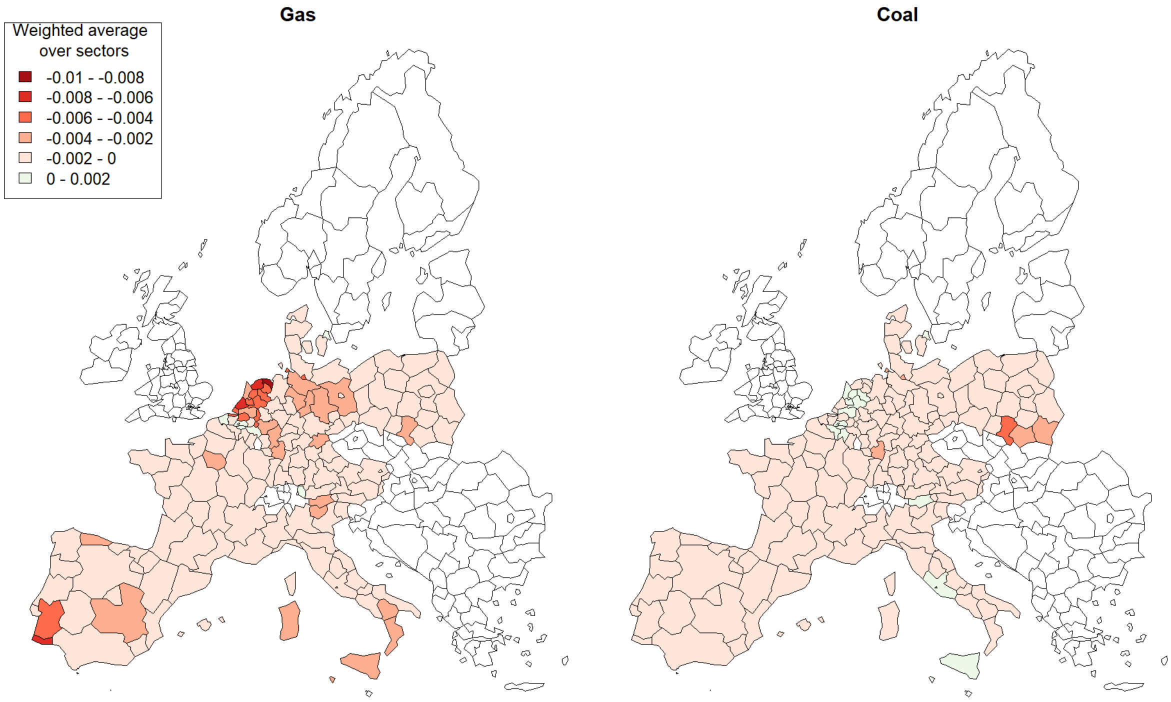

Figure 6: The elasticity of a European user price of gas (left) or coal (right) on the competitiveness of European NUTS 2 regions.

Note: *The weighted average is computed over the production of the sectors traditional materials, low- and medium-technology industry, high-technology industry and chemical industry within the region. The price increase assumes that all fossil fuels used in production in European regions is 'taxed' or becomes more expensive.*

5.3 Increasing resilience by decarbonizing

The effect of decarbonization on regional resilience is studied by a change in the price elasticity, after a reduction of use of fossil energy in production. Specifically, we study a change in the use of gas and to focus on the low- and medium-technology industry sector, due to the large indirect fossil energy use (see Figure 2) and large share in regional output (see Figure 3). However, the methodology can be applied to any proposed change in a product on the resilience of regional competitiveness. Two different scenarios are considered: (1) an efficiency increase (e.g. less gas is necessary to produce the same product), (2) an increase in electrification, where gas is substituted for electricity. In what follows, we do not consider the technological feasibility of the efficiency or electrification in production, but take this as given, and we do not take into account the costs of realizing this change in the production process. We compute the relative percentage change of the global price elasticity such that the negative or positive value of the price elasticity is maintained and the value indicates the extent to which resilience has increased or decreased due to the decarbonization efforts.

5.3.1 Own production process

First, we consider an efficiency increase in the production process, such that the direct use of gas in the production of the sector which competitiveness we study decreases. Figure 7 shows the changes in the global price elasticity for gas in case the production process is made more efficient in all industrial sectors (weighted average, left) or only in the low- and medium-technology industry sector (right). The cost increase of the sector that is becoming more efficient is now limited, which results in increased resilience. The size of the effects varies, where there are opportunities for regions which we have seen are vulnerable to gas price shocks (see Figure 4), such as regions in the Netherlands, to turn this negative dependency into a positive opportunity to gain competitiveness if efficiency improvements are sufficient. Additional analyses show that an efficiency improvement of around 20% would suffice in turning the sign of the global price elasticity, becoming more efficient in gas use than competitors. This supports the discussion by Esty and Porter (1998), which states that adopting industrial ecology concepts within firms can increase their competitiveness. Additionally, however, we show that this also increases resilience to future shocks: an additional benefit of increasing resource productivity.

Electrification of the production process, that is, replacing gas with electricity, has much smaller effects on the resilience, as the replacement options may still make use of gas. It is important to note, however, that we do not take into account the costs of realising the efficiency or electrification in the production process, hence, this should not be seen as a full cost-benefit analysis. Replacing raw natural gas for electricity, where the electricity generation makes use of natural gas as well, can result in only a small reduction in dependency on natural gas in the supply chain as a whole. The price increase of gas is passed on in the electricity price and hence may still affect the cost price of the industry under consideration. Figure 8 shows the changes in the global price elasticity for gas in case of electrification in all industrial sectors (weighted average, left) or only in the low- and medium-technology industry sector (right).

5.3.2 Upstream production process

Finally, we look at how efficiency improvements or electrification upstream in the production process can affect the resilience to gas price shocks in the downstream sectors. We consider the low- and medium-technology industry as the indirect fossil use is large in this sector. Figure 9 shows the cases where efficiency increases in upstream sectors have a large effect on the resilience of the low- and medium-tech industry sector. The full set of results is included in the Appendix in Figure 22.

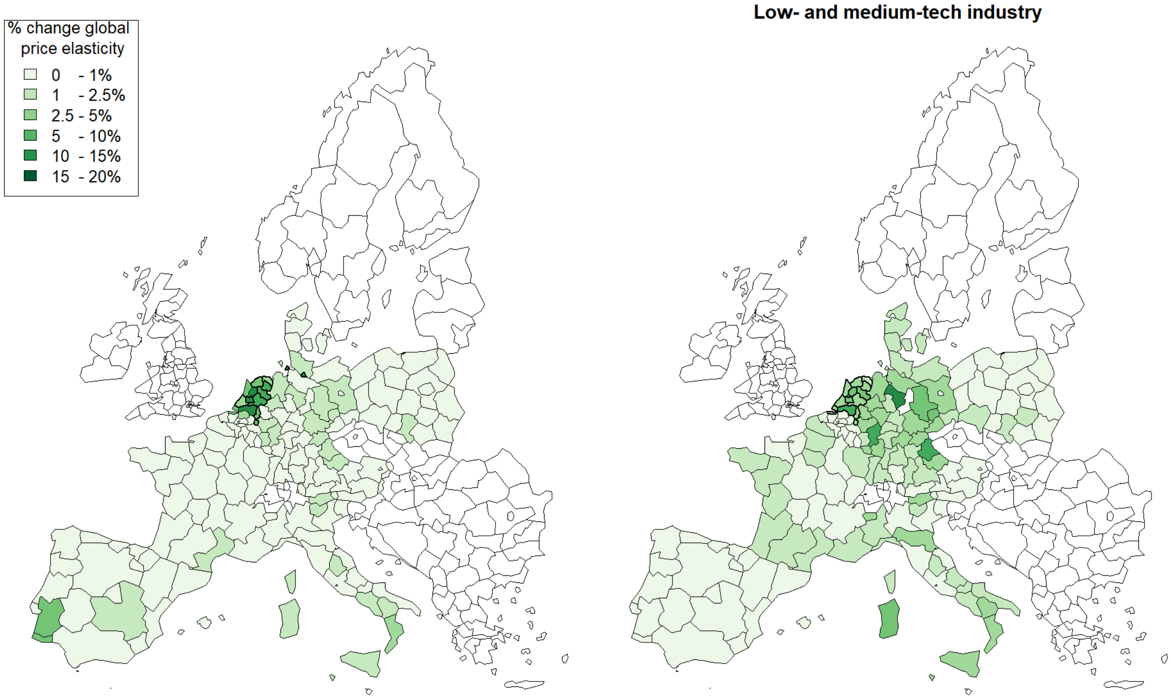

Figure 7: The effects on resilience of increased efficiency of 1% in all industrial sectors, weighted average (left) or only in low- and medium-technology industry in the region (right).

Note: *The 1% reduction is 1% of the current use of gas for producing 1 euro of the product. Regions with a* ***bold*** *border have negative global price elasticities (e.g., are vulnerable in terms of the competitive position to global price shocks).*

Electricity is an important input into production, and thus an improvement in efficiency can reduce the cost increase the firms experience significantly. However, we observe that the direction of the effect on resilience depends whether the European electricity generation becomes less gas-intensive, or whether this happens outside of Europe. In the first case, this benefits most European regions, as the change in the global price elasticity is on average positive. This presents competitive opportunities when efficiency increases take place. However, simultaneously, there is a threat of the electricity generation outside of Europe getting less gas-intensive: relatively, the European regions are then relying more on gas in electricity and therefore the vulnerability increases. A similar story holds for the oil refinery and cokes production. Interestingly, in traditional materials, the European regions do also make use of inputs from outside of Europe, creating heterogeneous effects from a gas efficiency increase. Figure 25 in the appendix shows that the positive effects on resilience for the low- and medium-technology industry sector occurs in regions that have large industrial sectors and that are possibly competing internationally, and thus using more inputs from outside of Europe. The smaller regions, with smaller industrial sectors, probably source more of their inputs within Europe and thus only experience negative effects from increased competition on the resilience.

The electrification scenario results for upstream sectors are plotted in Figure 10 (full results in Figure 27 in the Appendix). Here, in terms of size, the effects on the sensitivity of competitiveness or the price elasticity is a lot smaller than the case of efficiency, where a 1% efficiency increase can already reduce the vulnerability or increase the opportunities of a price shock by

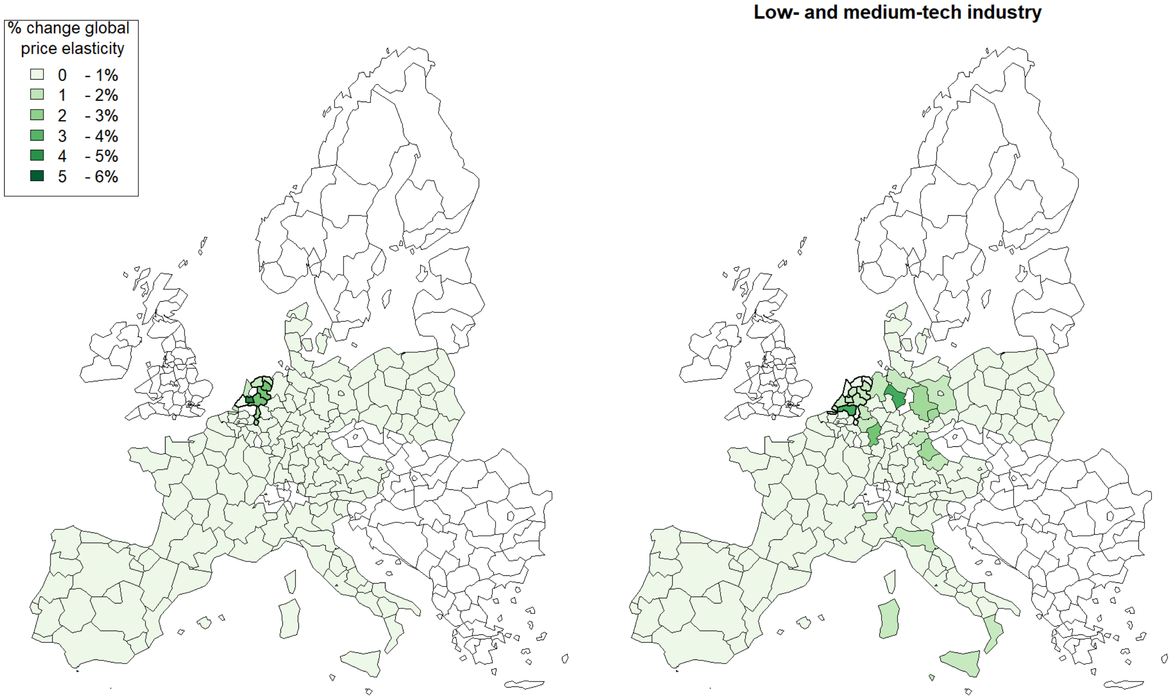

Figure 8: The effects on resilience of increased electrification of 50% in all industrial sectors, weighted average (left) or in only low- and medium-technology industry in the region (right).

Note: *The 50% reduction is 50% of the current use of gas for producing 1 euro of the product. Regions with a* ***bold*** *border have negative global price elasticities (e.g., are vulnerable in terms of the competitive position to global price shocks).*

a lot more. For most sectors within the country or in the same region the patterns and relative sizes are comparable to the efficiency scenario. However, the location-specific electrification effects on resilience in several upstream sectors is more proclaimed. In the case of electrification in private services, transport and traditional materials industries, if this occurs outside of the own country considered, the resilience is more negatively affected than in the efficiency case. This is due to the gas dependency in electricity generation in most European regions. Competitors may be better able to reduce the dependency of gas by electrification.

6 Conclusion

Recent fluctuations in gas prices have made the dependency of economies on gas a reason for concern. The large volatility in gas price projections suggest that future price spikes may be unavoidable (IEA, 2023). Due to historical patterns, regional economies are to a varying degree specialized in energy-intensive industries. This implies large variation in dependency on fossil fuels depending on the structure of the region. Increasing regional resilience to shocks is becoming an important policy objective to limit the potential damages from future shocks, whereas a shift towards a green economy and the consequent transformation of the energy system can help in increasing this resilience. In this paper, we analyzed the sensitivity of regional competitiveness to changes in fossil fuel costs and explored how decarbonization initiatives can increase resilience.

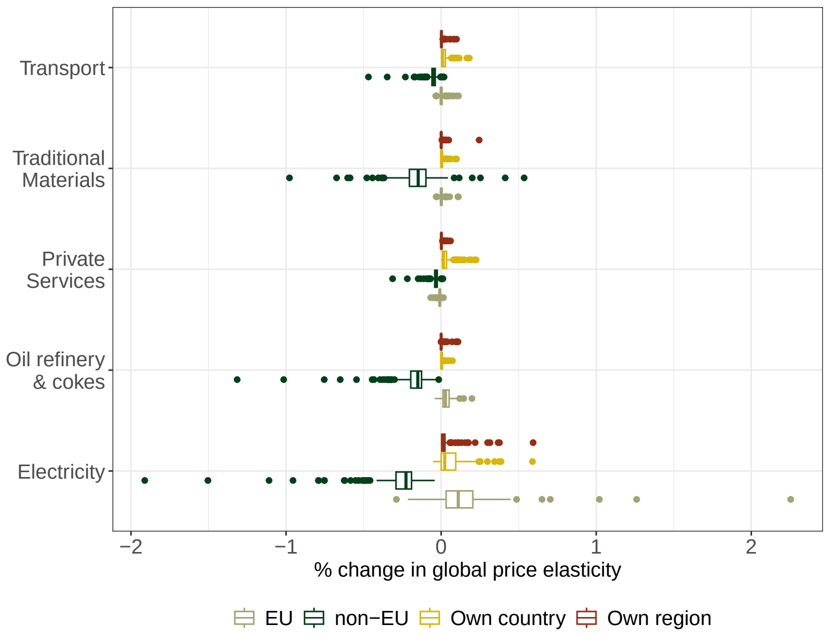

Figure 9: The percentage change in the global price elasticity of competitiveness for the low- and medium technology industry from a 1% efficiency increase of gas in the upstream sectors presented on the y-axis and the source of the sector in the regions denoted by various colors.

> *Note*: *The 1% reduction is 1% of the current use of gas for producing 1 euro of the product in the production of the upstream sector in the indicated region (in Europe, outside of Europe, or within the country the respective region is in.*

We presented a novel model for regional cost competition (RCC), combining an input-output price model and the revealed competition measure developed in Thissen et al. (2013). Using new Supply and Use tables with detailed energy products, we solve the non-linear model and obtain (i) a price elasticity on the RCC, showing whether the competitiveness of a region increases or decreases after a price increase, and (ii) an effect on resilience of a change in the use of gas in the production process.

The results show that regions in Europe are resilient to global coal price increases, suggesting a low dependency on coal, whereas they are more vulnerable to natural gas price shocks in terms of their competitive position. The size of the total effect on the regional industrial competitiveness in the case of a global gas price shock is negative in a few regions. Vulnerable regions either have a large dependency on gas in electricity generation and a historical pattern of gas intensity in production or specialized in energy-intensive industries. The traditional materials sector in the European regions is positively affected in terms of the competitive position by global fossil fuel price shocks. Thus, the sector is efficient in its use of fossil fuels compared to competitors, suggesting it is operating at the technological frontier.

The traditional materials sector in the European regions, which includes the basic metals industry such as steel production, is positively affected in terms of the competitive position by price shocks of both gas and coal when competitors experience a similar price increase. This implies that in Europe, this sector is very efficient in its use of fossil fuels compared to competitors, suggesting it is operating at the technological frontier.

In the case of a user end-price shock for gas and coal in Europe, competitiveness of the

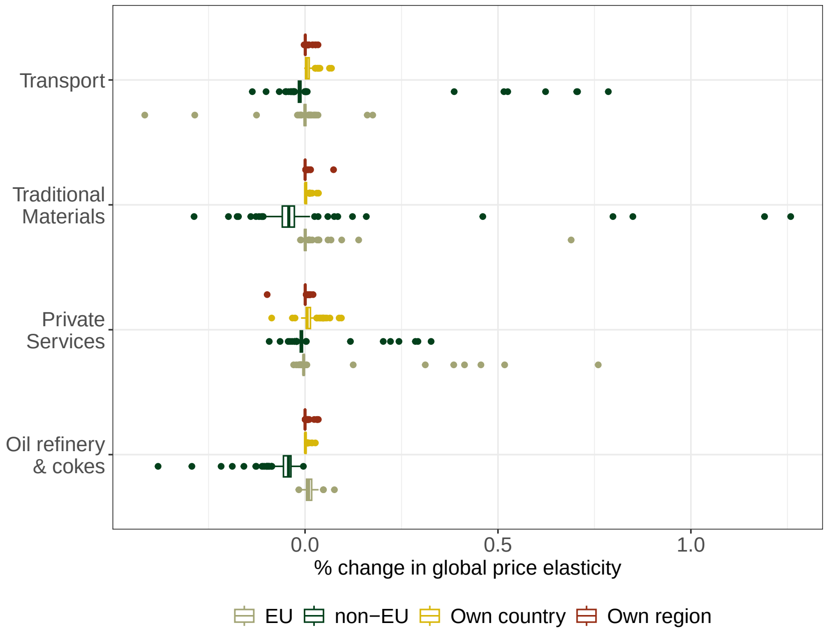

Figure 10: The percentage change in the global price elasticity of competitiveness for the low- and medium technology industry from a 50% substitution of gas for electricity in the sectors presented on the y-axis.

> *Note*: *The 50% electrification is 1% of the current use of gas for producing 1 euro of the product in the production of the upstream sector that is replaced with electricity, in the indicated region (in Europe, outside of Europe, or within the country the respective region is in.*

European regions is decreased. Again, a low dependency on coal ensures a limited loss in terms of competitiveness, whereas a gas price shock can have more severe effects. The extent to which a region is affected by the European price shock depends on the location of the competitors and which inputs it is using in production. However, as our first analysis with the global price increase has shown, many regions are operating at the technological frontier and are efficient in their use of fossil fuels. A loss in competitiveness of these regions and a reallocation of production to locations where the technology is less efficient, could thus result in less efficient use of fossils (often referred to as the carbon leakage effect). In our framework, however, we consider a short-term full cost pass-through and thus do not consider such mechanisms.

We consider improvements in efficiency in the use of gas and electrification in the production process, and investigate whether this increases resilience. We both look at the changes in the production process in the own sector, and what would happen in case the changes occur upstream of the sector under consideration. In the first case, the own sector effects are always positive, as cost increases are suppressed by using less gas. Large enough efficiency improvements can result in a negative effect of competitiveness to gas price shocks to a positive effect, increasing competitiveness. Thus, as previously discussed by Esty and Porter (1998), adopting industrial ecology concepts within firms can increase their competitiveness. Additionally, however, we show that this also increases resilience to future shocks: an additional benefit of increasing resource productivity. Electrification, however, has much smaller effects on the resilience.

At the same time, these results show that if competitors become more efficient in the use of gas (e.g., get closer to the technological frontier), this could decrease resilience. It is therefore important to not stay behind in such improvements to limit the effects of future gas price shocks.

Analyzing efficiency and electrification in upstream sectors provide insights in the dependencies of regions on the value chain. Increasing the efficiency of the use of gas in electricity generation and oil refinery and cokes production within the same region, country or in Europe, can increase resilience for the low- and medium-tech industry in most European regions. Thus, international cooperation may be warranted to reduce the reliance on natural gas which may affect the resilience of downstream sectors positively. However, if such improvements occur outside of Europe, where these inputs are mostly used by competitors of the European regions, resilience decreases.

In the case of electrification, the size of the effect on resilience is a lot smaller, but patterns remain the same. However, electrification can result in larger benefits for competitors, due to the gas intensity in European electricity generation, and can thus pose as a risk for the European regions in terms of future gas price shocks. In the long-run, electrification may have larger benefits, as the electricity generation mix may shift more towards renewable energy. However, various studies and policy discussions report that the role of gas in electricity generation may still be significant in the upcoming years, to serve as a flexible way to generate electricity in case of unmet demand by renewables. This suggest that the dependency on gas may remain large.

Thus, the contribution of this paper is twofold. First, we provided a new model and methodology to study price shocks and changes in the inputs used in production in an input-output framework which can be applied to a range of other research questions. Second, we provided insight into the intricate relationships between energy price fluctuations and competitive dynamics at the regional and industry levels. This analysis allowed us to identify the specific threats and opportunities that arise from these changes, taking into account the interplay of technological advancements, dependency and shifts in energy types.

Appendix

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Technical description splitting up SUTs

We create detailed Supply and Use tables (SUTs), and as a next step a detailed MRIO table, by disaggregating the regional supply and use tables from Thissen et al. (2023). The row containing the value of products in the category 'Mining and quarrying' (NACE Rev 2. or CPA code B) are split up into the sub-products related to fossil energy: hard coal, brown coal and lignite, oil, natural gas, natural gas liquids (NGLs) and other mining and quarrying products. Furthermore, the electricity, gas and steam product category (D35) is split into 'Electricity, trnasmission and distribution services' and 'Other energy'. The columns of the SUTs, indicating the sectoral structure, remains the same. Thus, instead of the 'Mining and quarrying' sector only producing 'Mining and quarrying' products, the sector now produces a certain amount of fossil energy types and other mining and quarrying products. The resulting disaggregated SUTs (1) by design sum up to the original tables and (2) are by design fully balanced.

The aggregation of the sectors in the supply and use tables to these sectors is presented in the appendix in Table 1.

1. The rows of the use table are split up using technological coefficients from various data sources. For each specific product, the amount that is used of that product in the production of a specific sector is used to split up the rows. Various data sources are combined: the supply and use tables for the U.S. and Japan, which include more sectoral and product detail than the original tables from Thissen et al. (2023), and the IEA World Energy Balances database for specific energy commodities[5]. First, the average of the U.S. and Japanese tables is used for those rows and columns where data is available[6] . Second, the available IEA data is used to fill the products and sectors that are related to energy use and generation. After this step, the required fossil energy inputs or use for every region is determined.

2. The imports per region for each product are determined. The imports per sub-product are constructed by the regional demand shares per sub-product and the total regional imports of the whole product group. Using regional level data from the structural business statistics from Eurostat[7], we apply constraints for regions where no production/mining of fossil energy sources takes place. In this case, all regional demand (determined by the sum of the use based on regional production from the previous step) has to be imported.

3. A trade prior and an export prior is constructed. The trade prior is based on the demand for fossil inputs that is determined in the first step. For the trade flows, bilateral trade data from BACI is used to split the original, aggregated trade flows (Gaulier and Zignago, 2010). For the export prior, the total demand for the exports is given by the sum of the use table minus the imports (and we exclude the stocks, so that we do not obtain negative values). However, when data is available we make use of the BACI trade data to split up the exports. When the exports in the BACI trade data are zero (for example for various

[5] The IEA World Energy Balances database is available here.
[6] The Japanese input-output tables are available here
[7] Available here

mining categories), we enforce this zero exports such that in the next step these exports cannot be adjusted to match the trade flows and imports.

4. A NLP program finds the bilateral trade flows and exports, starting from the priors, such that the difference between the resulting exports and initial exports prior is minimized and satisfy the following constraints:

   (a) The estimated exports for a product in the region are equal to the sum of outgoing trade flows to all other regions.

   (b) The fixed imports are equal to the sum of incoming trade flows in the region.

   (c) The sum of detailed resulting exports is equal to the exports in the original Supply and Use tables.

   The outcomes of the NLP are checked for consistency. We set a constraint to avoid re-exports and re-imports. The objective function that is used is the root mean square weighted error and percentage error method (RMSWEPE) proposed in Thissen et al. (2013) and discussed in Thissen et al. (2023).

5. The rows of the supply table are split using a proxy for domestic demand per sub-product (total demand for the product is the sum of total use) over the total domestic demand per product group.

The final, detailed supply and use tables are then aggregated to the chosen product aggregation (see Table 1 and regional aggregation to create a product-by-product input-output table.

Additional tables and figures

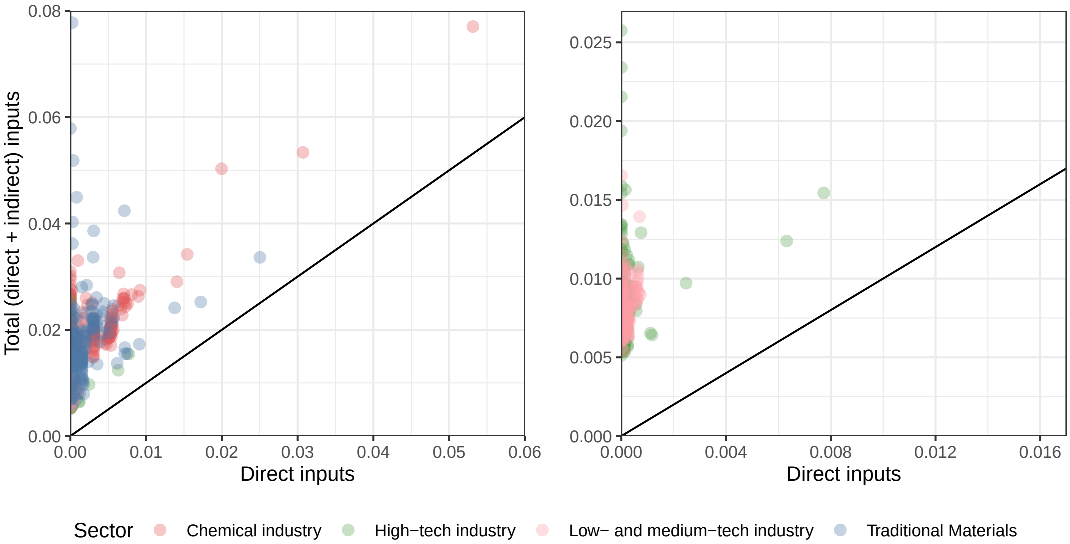

Figure 11: Coal input in production per sector (in Euros per 1 Euro of production).

Note: *The resulting direct use of coal per NUTS 2 region per sector plotted against the total use of coal throughout the value chain.*

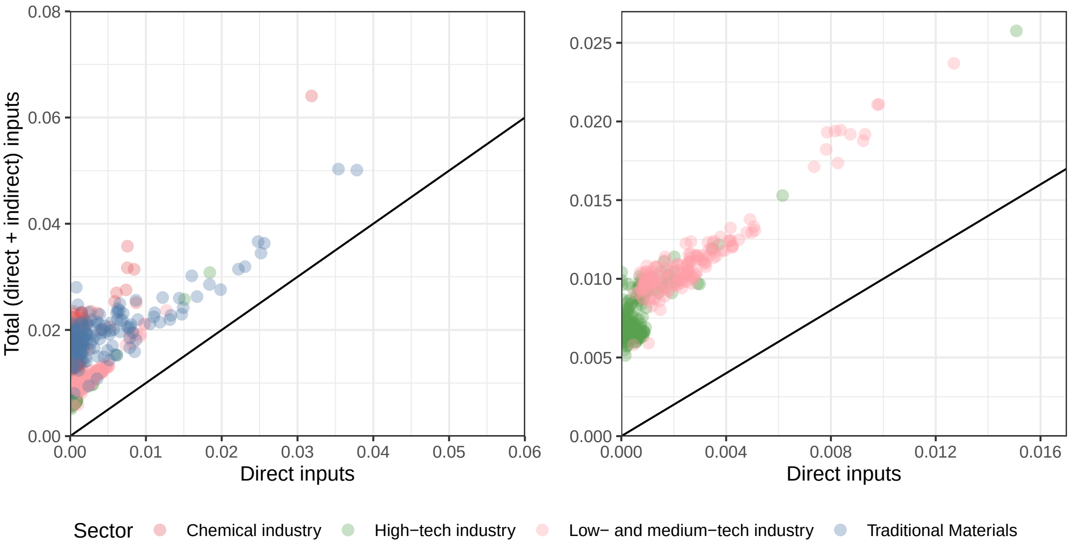

Figure 12: Gas input in production per sector (in Euros per 1 Euro of production).

Note: *The resulting direct use of gas per NUTS 2 region per sector plotted against the total use of gas throughout the value chain.*

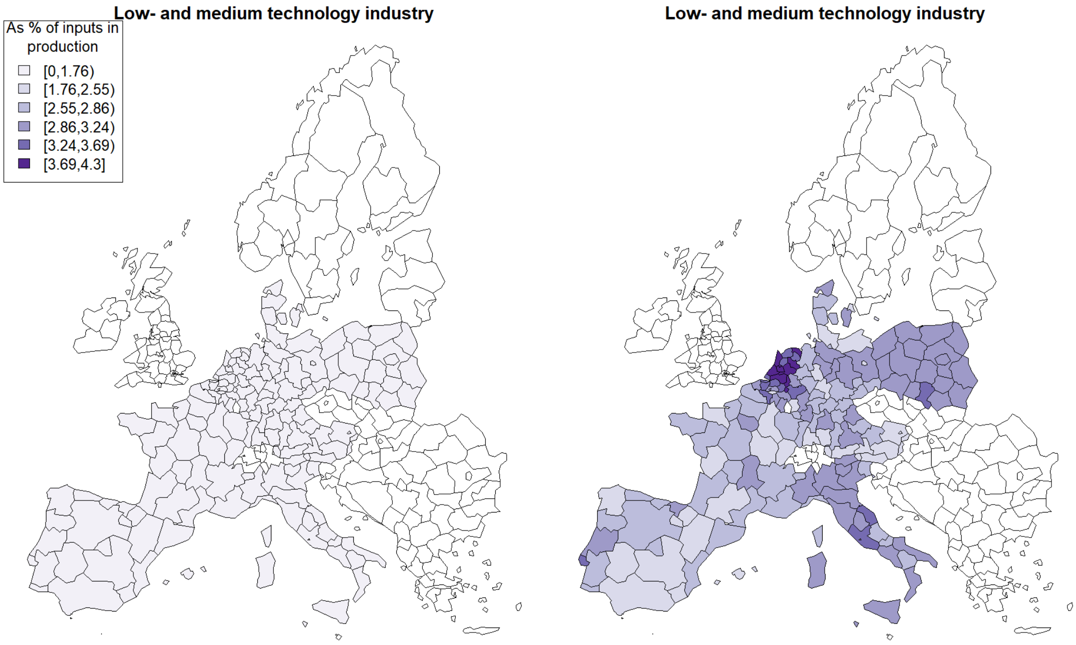

Figure 13: The direct use (left) and total use (right) of fossils per NUTS 2 region in low- and medium-technology industry.

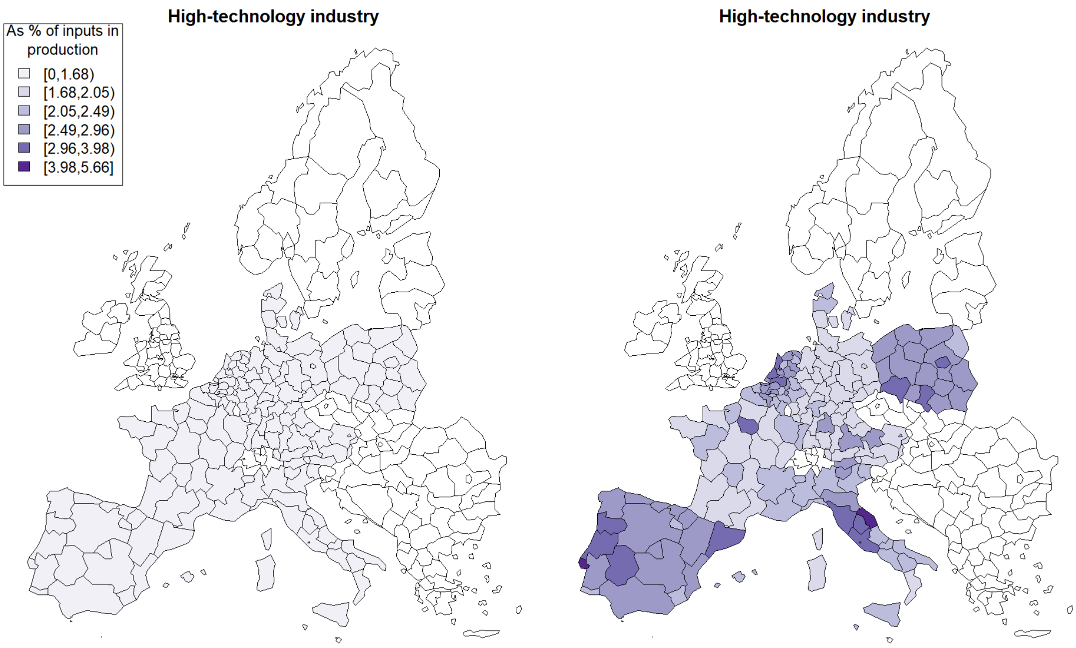

Figure 14: The direct use (left) and total use (right) of fossils per NUTS 2 region in high-technology industry.

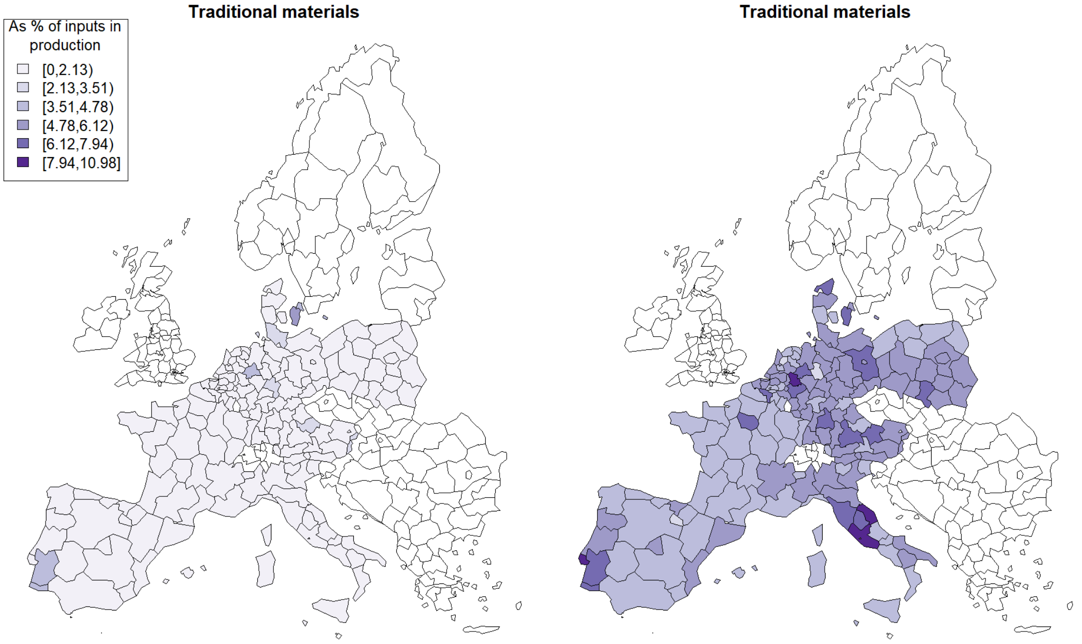

Figure 15: The direct use (left) and total use (right) of fossils per NUTS 2 region in traditional materials industry.

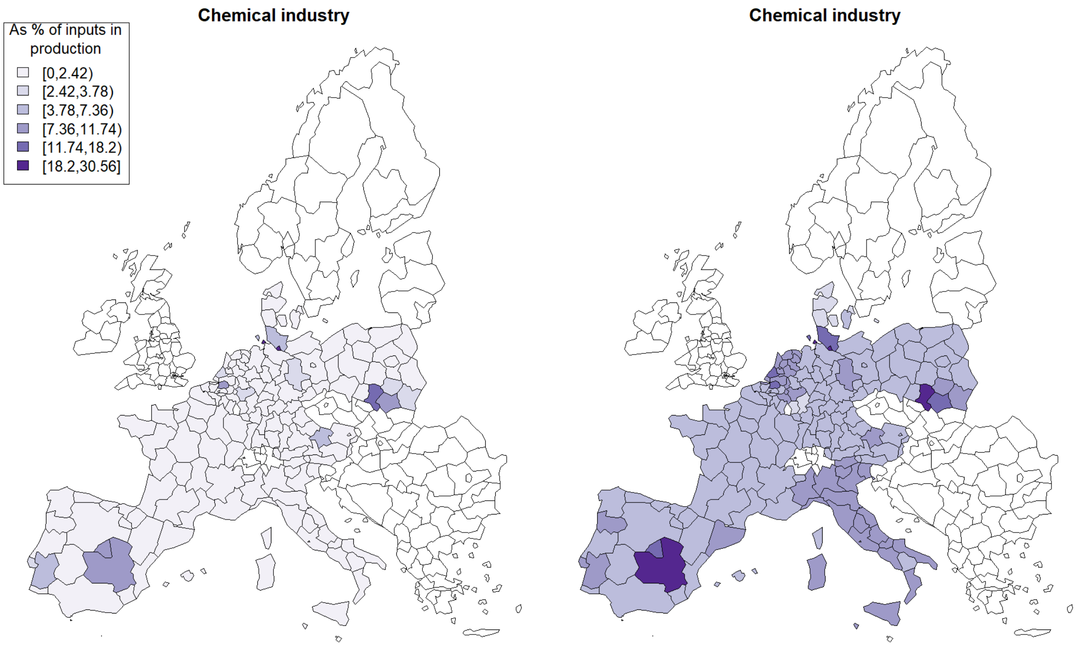

Figure 16: The direct use (left) and total use (right) of fossils per NUTS 2 region in chemical industry.

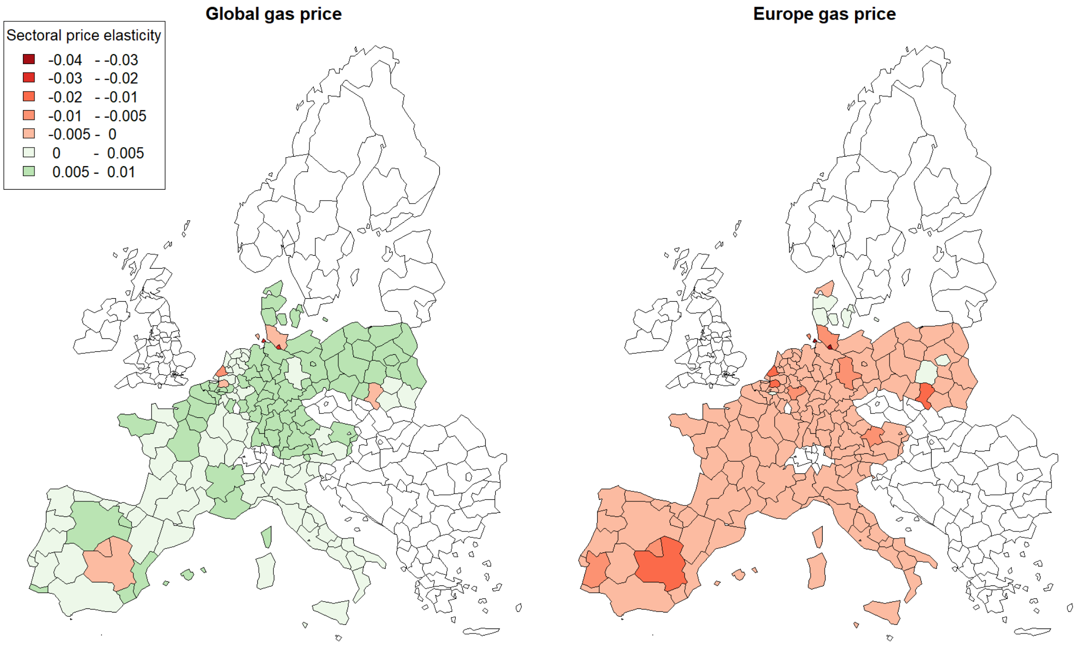

Figure 17: Competitiveness effects of the chemical industry of global and European price changes.

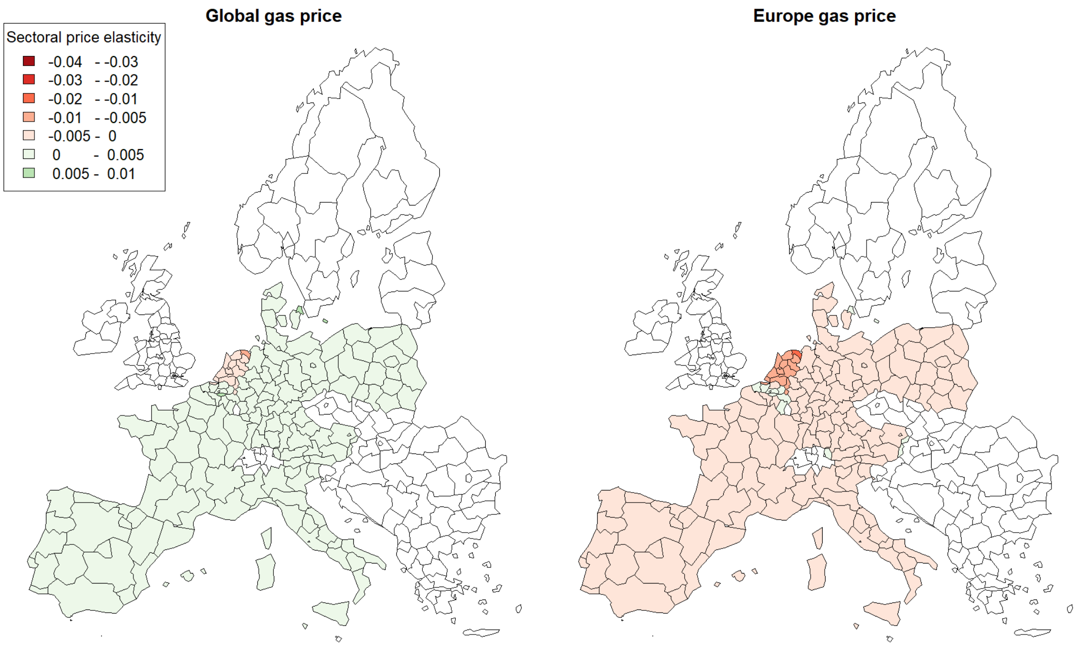

Figure 18: Competitiveness effects of the low- and medium-tech industry of global and European price changes.

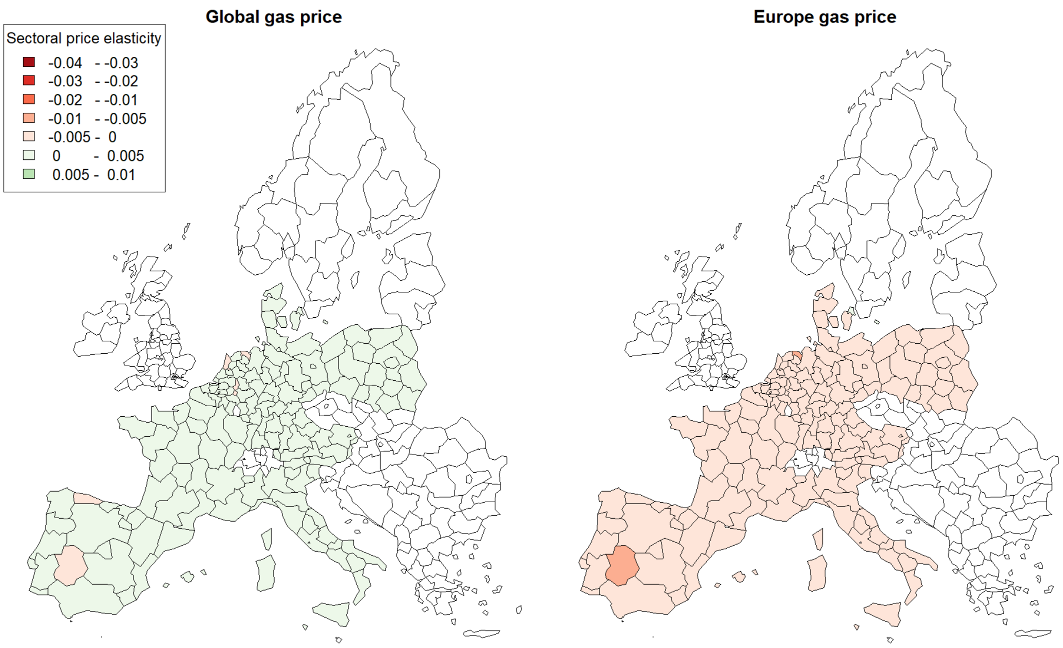

Figure 19: Competitiveness effects of the high-tech industry of global and European price changes.

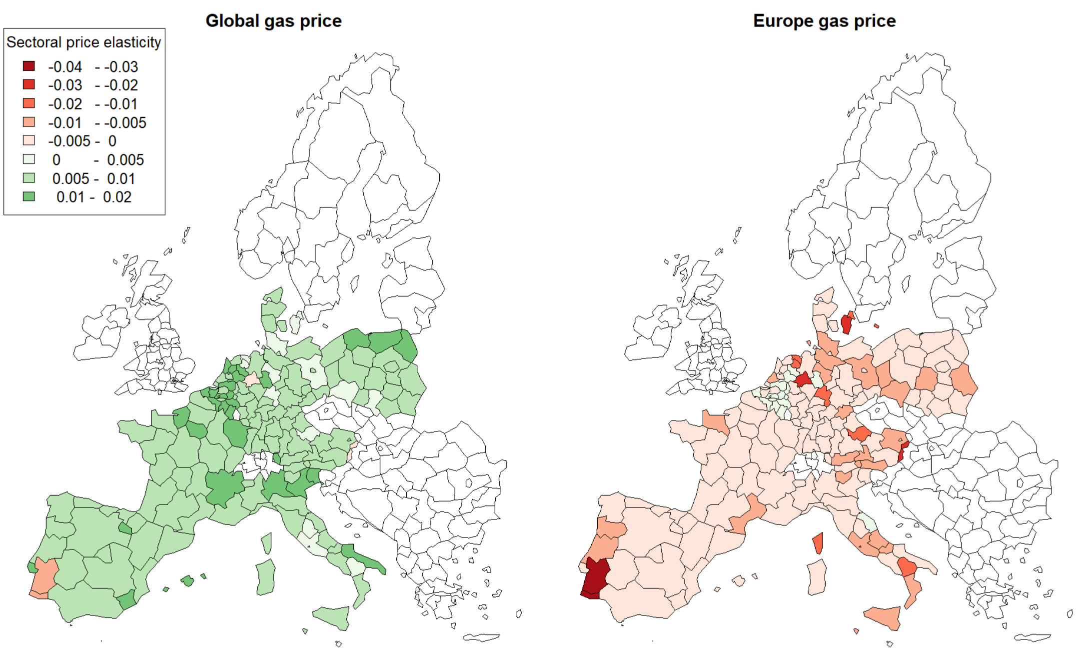

Figure 20: Competitiveness effects of the traditional materials industry of global and European price changes.

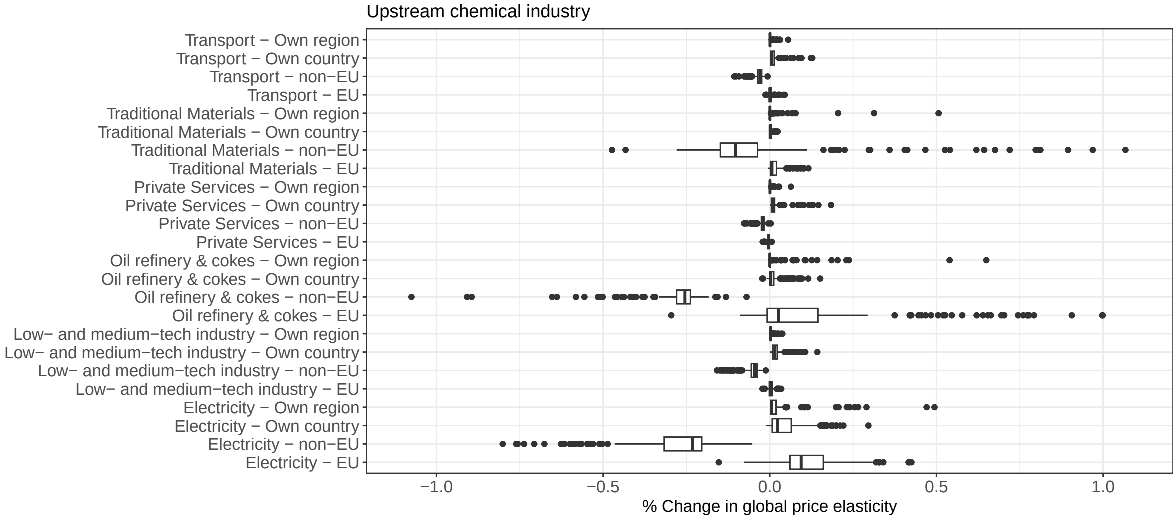

Figure 21: Resilience effects of a 1% efficiency increase upstream for the chemical industry.

Note: *The horizontal axis presents the percentage change in the global price elasticity of competitiveness for the chemical industry from a 1% efficiency increase of gas in the upstream sectors. The upstream sector and its location under consideration is presented on the y-axis. The 1% reduction is 1% of the current use of gas for producing 1 euro of the product in the production of the upstream sector in the indicated region (in Europe, outside of Europe, or within the country the respective region is in).*

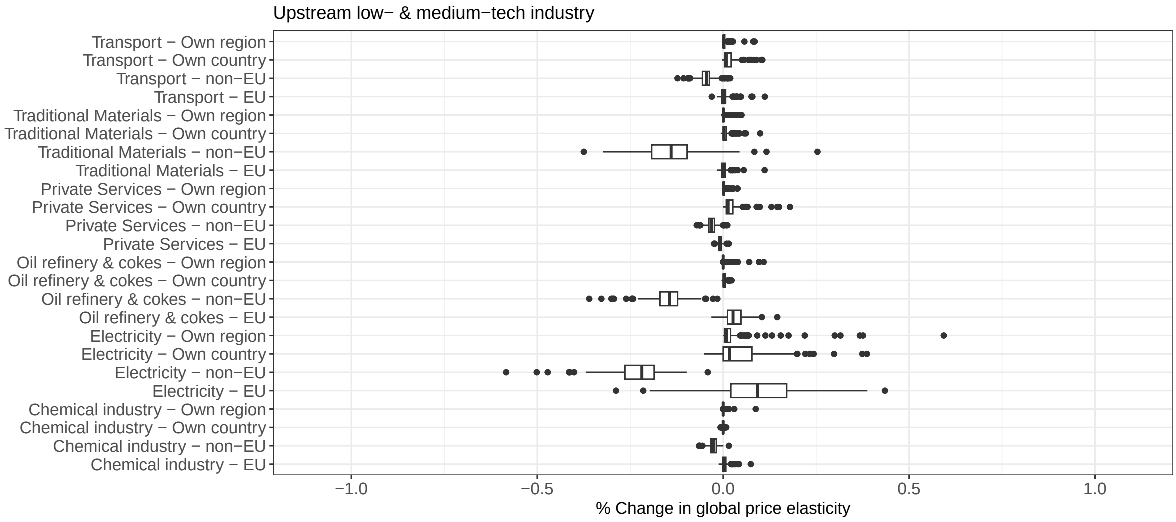

Figure 22: Resilience effects of a 1% efficiency increase upstream for the low- and medium-tech industry.

Note: *The horizontal axis presents the percentage change in the global price elasticity of competitiveness for the low- and medium-tech industry from a 1% efficiency increase of gas in the upstream sectors. The upstream sector and its location under consideration is presented on the y-axis. The 1% reduction is 1% of the current use of gas for producing 1 euro of the product in the production of the upstream sector in the indicated region (in Europe, outside of Europe, or within the country the respective region is in).*

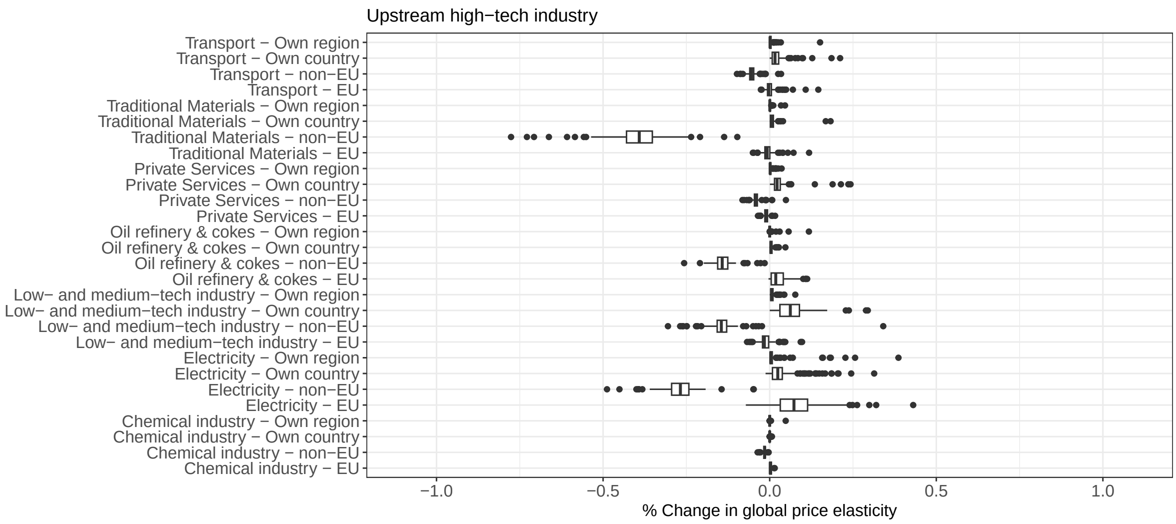

Figure 23: Resilience effects of a 1% efficiency increase upstream for the high-tech industry.

Note: *The horizontal axis presents the percentage change in the global price elasticity of competitiveness for the high-tech industry from a 1% efficiency increase of gas in the upstream sectors. The upstream sector and its location under consideration is presented on the y-axis. The 1% reduction is 1% of the current use of gas for producing 1 euro of the product in the production of the upstream sector in the indicated region (in Europe, outside of Europe, or within the country the respective region is in).*

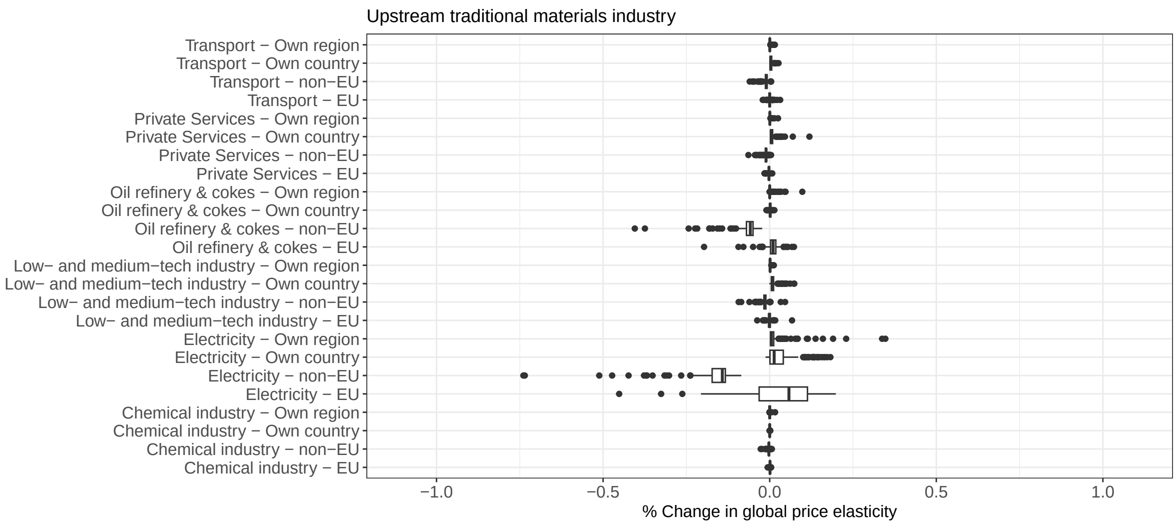

Figure 24: Resilience effects of a 1% efficiency increase upstream for the traditional materials industry.

Note: *The horizontal axis presents the percentage change in the global price elasticity of competitiveness for the traditional materials industry from a 1% efficiency increase of gas in the upstream sectors. The upstream sector and its location under consideration is presented on the y-axis. The 1% reduction is 1% of the current use of gas for producing 1 euro of the product in the production of the upstream sector in the indicated region (in Europe, outside of Europe, or within the country the respective region is in).*

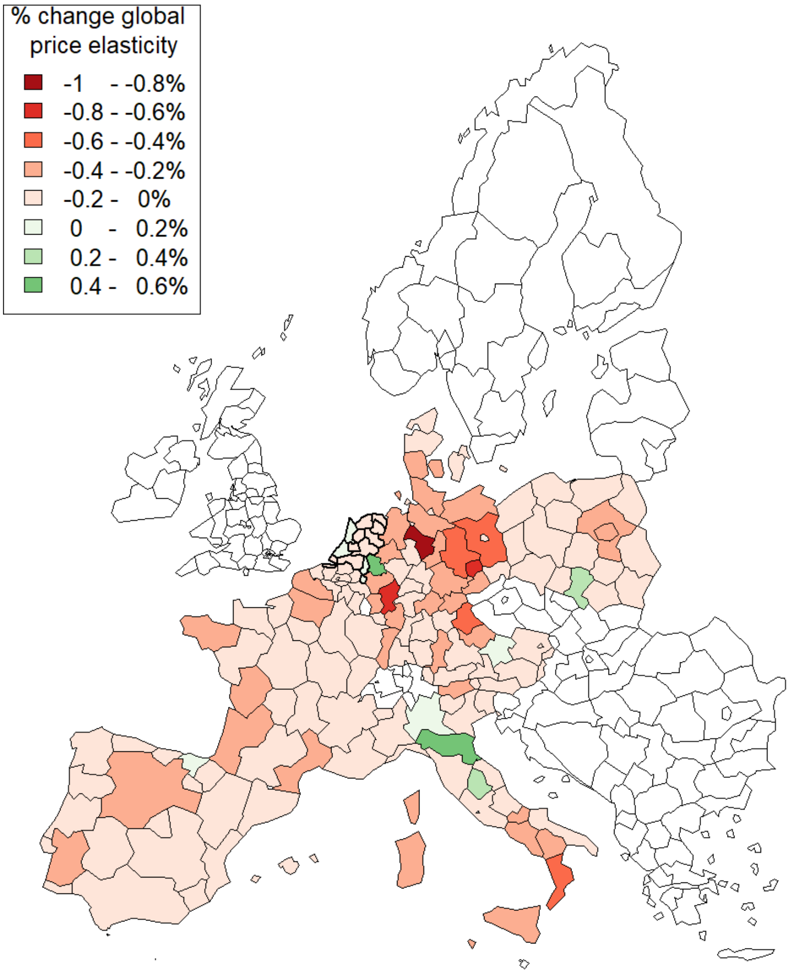

Figure 25: Resilience effects of a 1% efficiency increase in traditional materials outside of Europe for the low- and medium-technology industry.

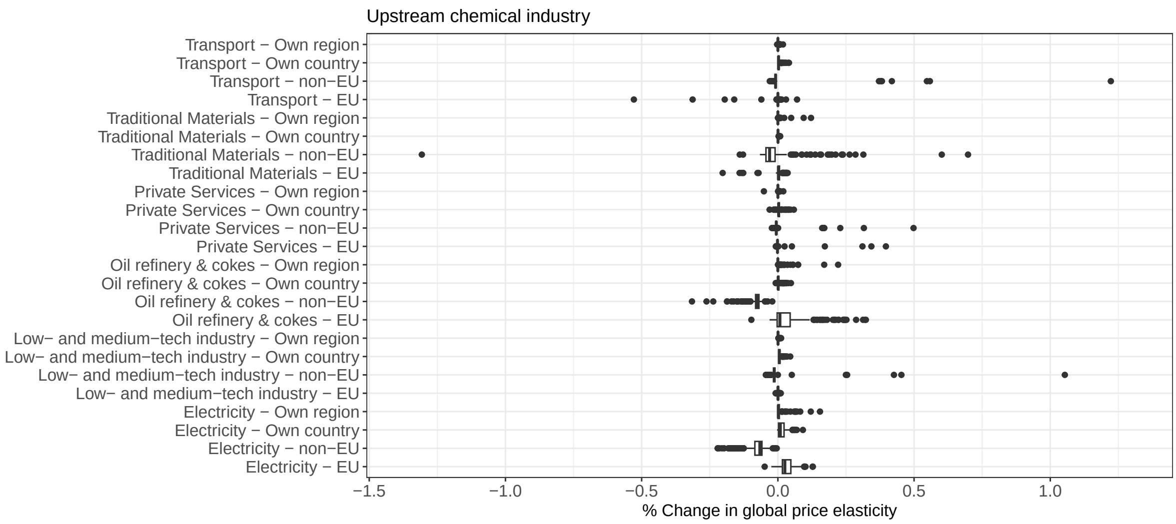

Figure 26: The effects of a 50% electrification upstream for the chemical industry sector in various regions (own region, own country, outside Europe or inside Europe).

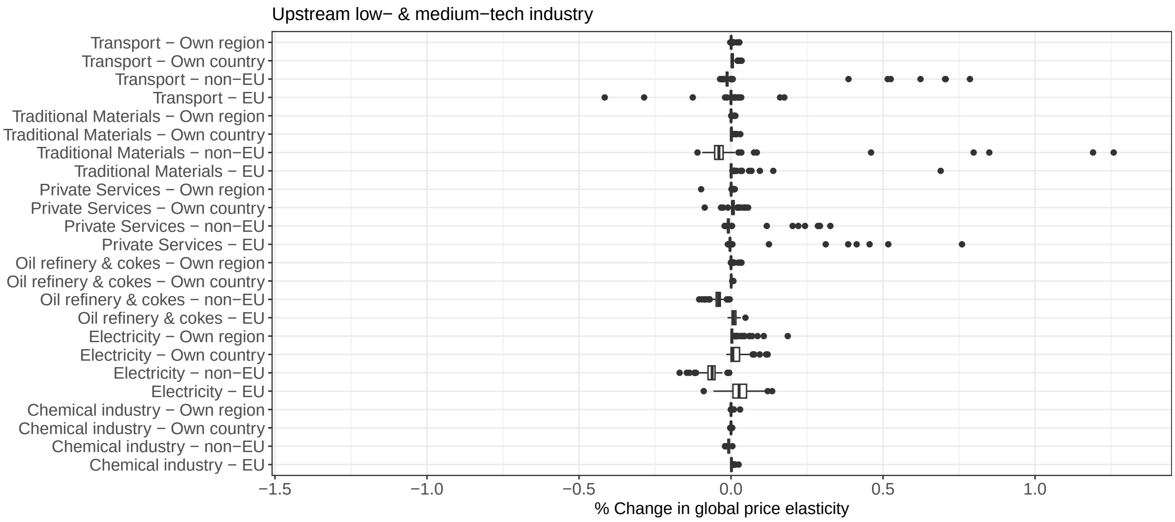

Figure 27: Resilience effects of 50% electrification upstream for the low- and medium-tech industry.

Note: The horizontal axis presents the percentage change in the global price elasticity of competitiveness for the low- and medium technology industry from a 50% substitution of gas for electricity in the sectors presented on the vertical axis. The 50% electrification is 50% of the current use of gas for producing 1 euro of the product in the production of the upstream sector that is replaced with electricity, in the indicated region (in Europe, outside of Europe, or within the country the respective region is in).

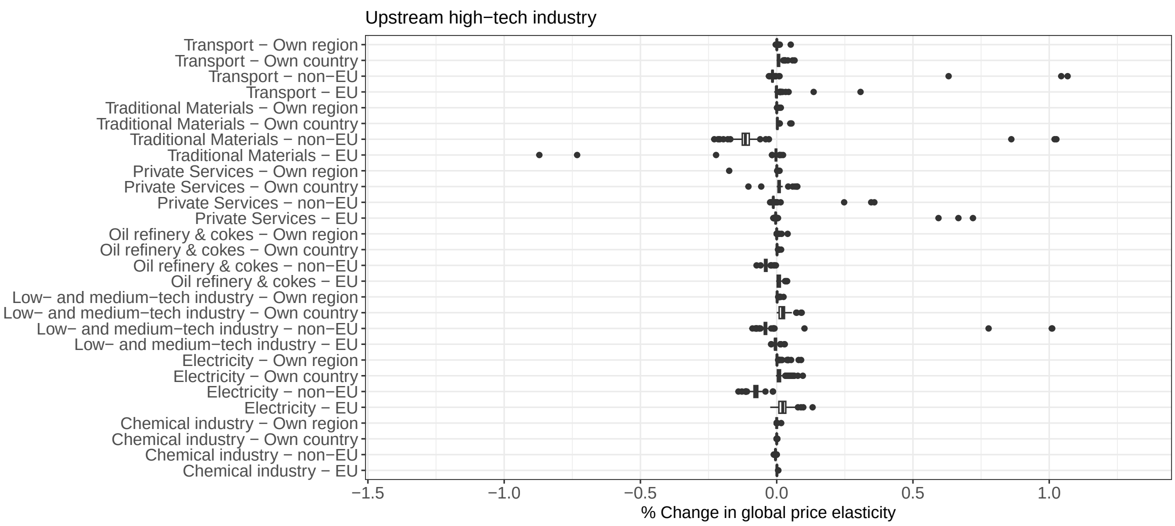

Figure 28: Resilience effects of 50% electrification upstream for the high-tech industry.

Note: The horizontal axis presents the percentage change in the global price elasticity of competitiveness for the high-tech industry from a 50% substitution of gas for electricity in the sectors presented on the vertical axis. The 50% electrification is 50% of the current use of gas for producing 1 euro of the product in the production of the upstream sector that is replaced with electricity, in the indicated region (in Europe, outside of Europe, or within the country the respective region is in).

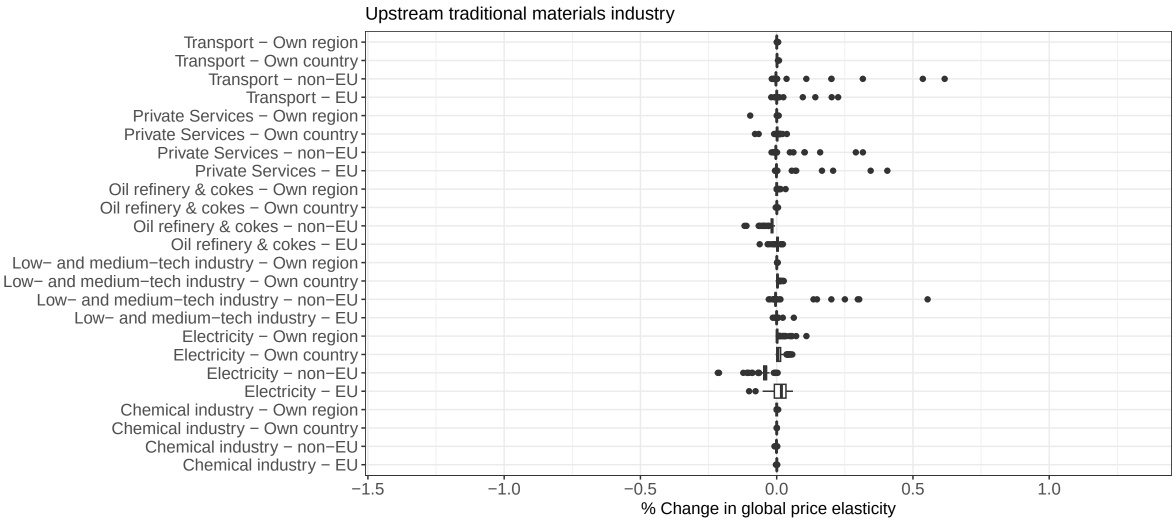

Figure 29: Resilience effects of 50% electrification upstream for the traditional materials industry.

Note: The horizontal axis presents the percentage change in the global price elasticity of competitiveness for the traditional materials industry from a 50% substitution of gas for electricity in the sectors presented on the vertical axis. The 50% electrification is 50% of the current use of gas for producing 1 euro of the product in the production of the upstream sector that is replaced with electricity, in the indicated region (in Europe, outside of Europe, or within the country the respective region is in).

Table 1: The product aggregation of the input-output table used.

CPA code	Description	Product group
A	Products of agriculture, forestry and fishing	Agriculture
B05.1	Hard coal	Coal
B05.2	Lignite	Coal
B06.1	Crude petroleum	Oil
B06.2	Natural gas, liquefied or in gaseous state	Gas
B07	Metal ores	Traditional Materials
B08	Other mining and quarrying products	Traditional Materials
B09	Mining support services	Other Energy
C10-C12	Food products, beverages and tobacco products	Low- & medium-tech
C13-C15	Textiles, wearing apparel, leather and related products	Low- & medium-tech
C16	Wood and of products of wood and cork	Low- & medium-tech
C17	Paper and paper products	Low- & medium-tech
C18	Printing and reproduction services of recorded media	Low- & medium-tech
C19	Coke and refined petroleum products	Oil refinery & cokes
C20	Chemicals and chemical products	Chemical industry
C21	Basic pharmaceutical products	Low- & medium-tech
C22	Rubber and plastic products	Low- & medium-tech
C23	Other non-metallic mineral products	Low- & medium-tech
C24	Basic metals	Traditional Materials
C25	Fabricated metal products	Low- & medium-tech
C26	Computer, electronic and optical products	High-tech industry
C27	Electrical equipment	High-tech industry
C28	Machinery and equipment n.e.c.	High-tech industry
C29	Motor vehicles, trailers and semi-trailers	High-tech industry
C30	Other transport equipment	High-tech industry
C31, C32	Furniture and other manufactured goods	Low- & medium-tech
C33	Repair & installation services of machinery & equipment	Private Services
D35.1	Electricity, transmission and distribution services	Electricity
D35.2, D35.3	Manufactured gas; distribution services of gaseous fuels through mains; steam & air conditioning supply services	Other Energy
E	Water supply; sewerage, waste management and remediation services	Public Services
F	Constructions and construction works	Private Services
G	Wholesale and retail trade services; repair services of motor vehicles and motorcycles	Transport
H51	Air transport services	Transport
H52	Warehousing and support services for transportation	Transport
H53	Postal and courier services	Private Services
I	Accommodation and food services	Private Services
J	Information and communication services	Private Services
K	Financial and insurance services	Private Services
L	Real estate services	Private Services
M	Professional, scientific and technical services	Private Services
N	Administrative and support services	Private Services
O - T	Public services	Public Services